GAS DYNAMICS LABORATORY
UILU-ENG-76-4003
DEPARTMENT OF MECHANICAL AND INDUSTRIAL ENGINEERING
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
URBANA, ILLINOIS 61801

THEORETICAL AND EXPERIMENTAL ANALYSIS OF THE CONSTANT-AREA, SUPERSONIC-SUPERSONIC EJECTOR

by

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OCTOBER 1976

Supported by
~~U.S. Army Research Office~~
Grant Number DAHC 04-75-G-0046
and
Department of Mechanical and
Industrial Engineering

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: UILU-ENG-76-4003	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): Theoretical and Experimental Analysis of the Constant-Area, Supersonic-Supersonic Ejector	5. TYPE OF REPORT & PERIOD COVERED: Final Technical Report 1 October 1974-15 January 1976
	6. PERFORMING ORG. REPORT NUMBER: UILU-ENG-76-4003
7. AUTHOR(s): C. D. Mikkelsen, M. R. Sandberg, and A. L. Addy	8. CONTRACT OR GRANT NUMBER(s): Grant DAHC 04-75-G-0046
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Department of Mechanical and Industrial Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: U. S. Army Research Office, Post Office Box 12211, Research Triangle Park, NC 27709	12. REPORT DATE: October 1976
	13. NUMBER OF PAGES: 284
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE: NA

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

NA

18. SUPPLEMENTARY NOTES

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Chemical Laser
Gas Dynamics
Ejector
Diffuser

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A preliminary theoretical and experimental analysis was conducted of the constant-area, supersonic-supersonic ejector wherein one supersonic stream is pumped directly by another inside a confining duct. The theoretical analysis, based on a one-dimensional treatment of the constant-area mixing section and inviscid interaction region, is well suited to parametric evaluations and ejector optimization procedures. The experimental investigation of four, small-scale, axisymmetric ejector configuarations show (i) that the one-dimensional

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theory predicts maximum ejector compression ratios which are approximately 15 to 20 percent higher than the corresponding experimental values and (ii) that this ejector appears to be particularly susceptible to secondary flow separation.

The one-dimensional analysis of the constant-area, supersonic-supersonic ejector was incorporated with a one-dimensional analysis of the conventional constant-area, subsonic-supersonic ejector into a pumping system optimization procedure applicable to high-energy, chemical laser systems and supersonic wind tunnel systems. A comparison of optimum pumping system data shows that under certain conditions, a supersonic-supersonic pumping system has the potential for improved performance over that of a subsonic-supersonic pumping system.

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Final Technical Report

by

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Supported by

U.S. Army Research Office

Grant Number DAHC 04-75-G-0046

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NOMENCLATURE

Symbols

A	Area.
C_P	Specific heat at constant pressure.
C_V	Specific heat at constant volume.
D	Diameter.
$f_1(\ ),\cdots,f_4(\ )$	Gas dynamic functions defined in text.
F	Force.
g	Gravitational constant.
h	Specific enthalpy.
M	Mach number.
Mw	Molecular weight.
P	Pressure.
Q	Heat.
r	Radial coordinate.
R	Radius.
Re	Reynolds number.
$\mathcal{R}$	Universal gas constant.
t	Time.
T	Temperature.
u	Specific internal energy.
v	Volume.
V	Magnitude of velocity.
W	Mass flow rate.
W_{ss}	Work, shaft and shear.
x	Longitudinal coordinate or flow-direction coordinate.

z	Elevation.
γ	Ratio of specific heats.
μ	Absolute viscosity.
ρ	Density.
$(\ )^*$	Signifies state at which the Mach number is unity.

Subscripts

0	Stagnation state.
1,2,3	System locations.
CS	Control surface.
CV	Control volume.
M	Mixed.
P	Primary.
S	Secondary.
T	Nozzle throat.
$(\ )_x$	Signifies quantity in the flow direction coordinate.

For Sections 4.2 and 4.3 only:

Symbols

$f(\ )$	Gas dynamic functions defined in text.
R_{NSD}	Normal shock diffuser coefficient.
η	Subsonic diffuser efficiency.

Subscripts

1	Laser cavity entrance location.
2	Laser cavity exit location.
3	Normal shock diffuser exit and subsonic diffuser entrance location

4	Subsonic diffuser exit location.
5	Secondary nozzle exit location.
6	Primary nozzle exit location.
7	Mixing tube exit and subsonic diffuser entrance location.
8	Subsonic diffuser exit location.

1.0 INTRODUCTION

This theoretical and experimental analysis of the constant-area, supersonic-supersonic ejector was prompted by current interest in the high-energy, chemical laser and the unique gas dynamic problems associated with that device.

In a typical high-energy, chemical laser, Figs. 1.0-1 and 1.0-2, hydrogen and flourine are precombusted to form free flourine atoms which, with the other gaseous products of combustion, accelerate into the laser cavity through a series of supersonic nozzles. Additional streams of secondary gases enter the laser cavity through a series of supersonic nozzles to form alternate interleaved streams of precombustor and secondary gases. These streams, initially at high Mach numbers (3 to 7) and low static pressures (5 to 200 Torr) mix and react to establish the lasing zone by chemically producing population inversions of selected species. Accompanying these chemical reactions, a significant quantity of heat is released into the laser cavity flow which tends, qualitatively, to increase the static pressure, to decrease the stagnation pressure, and to decrease the Mach number of the "mixed" supersonic flow. At the laser cavity exit, the hot ($T \approx 1500$ K), corrosive, supersonic ($1.5 < M < 3.5$) "mixed" flow at low pressure ($10 < P < 60$ Torr) must be "pumped" by some form of diffuser-ejector system to atmospheric discharge conditions (760 Torr) in order to start and sustain the lasing process. A pumping system which is ideally suited to this application would have:

1. A potential compression ratio in the range 80 to 8,
2. Simplicity of design with high resistance to hot, corrosive gases,

3. The capability to isolate the laser cavity flow from minor perturbations in the downstream conditions and/or pumping system,
4. The flexibility in operating point and performance to allow for variations in laser performance and flow conditions,
5. The capability for short-duration, transient start-up,
6. Minimum pumping resource requirements, and
7. Compact design with portability and mobility as goals.

Current high-energy chemical laser designs have incorporated the constant-area, supersonic diffuser coupled with the constant-area,subsonic-supersonic ejector, Fig. 1.0-3, as a pumping system since the operation of this system is fairly well understood while providing the most obvious, if not satisfactory, solution to the above requirements. Nevertheless, the quest for an improved pumping system continues with various modifications of the conventional diffuser-ejector as candidates [1].

One such candidate for a high-performance chemical laser pumping system is the supersonic-supersonic ejector, Fig. 1.0-4, the subject of this investigation. In this system, the diffuser is eliminated and the supersonic laser cavity stream is pumped directly by the ejector. Thus, the supersonic-supersonic ejector offers a potential alternative in that the desirable characteristics of the conventional diffuser-ejector are retained with a reduction of size and a possible increase in performance.

1.1 REVIEW OF PREVIOUS WORK

The ejector has been in use for many years; indeed, the literature is filled with a virtual multitude of ejector related papers*, the author

*See APPENDIX 7.0.

having compiled over 300 entries dating from 1892. With the exception of three supersonic wind tunnel studies, none of these papers, to the author's knowledge, have addressed the problem of pumping a supersonic stream directly by an ejector, which is not particularly surprising since most commercial applications involve the pumping of subsonic or nearly stagnate streams.

The three wind tunnel studies [2,3,4] were part of an experimental investigation to study the effects of auxiliary air injection on the pressure recovery of variable geometry, supersonic wind tunnel systems. In each case, the auxiliary air was injected through a supersonic nozzle at the downstream end of the supersonic test section, thus in essence forming a supersonic-supersonic ejector. The first two investigations [2,3] showed that the resultant pressure recovery with injection was not as good as those attained with variable-geometry diffuser tunnels; however, the later study by Hasel and Sinclair [4] demonstrated a significant improvement in total system pressure recovery with auxiliary injection.

The general methods of analysis employed in existent subsonic-supersonic ejector models apply equally well to the supersonic-supersonic ejector provided their application is consistent with the physical phenomena. These methods of analysis are:

1. The one-dimensional analysis,
2. The method-of-characteristics,
3. The method of integral relations, and
4. The finite-difference method.

In the one-dimensional model of the subsonic-supersonic ejector as executed by Fabri, et al. [5,6], the conservation equations were applied

to a control volume contained within the ejector mixing tube assuming uniform velocity and pressure distributions of the primary and secondary streams at the tube entrance and a uniformly mixed stream at the tube exit. A second control volume was used to predict the operation of the ejector when the secondary stream choked within the mixing tube. The primary and secondary streams were assumed to remain distinct and to be isentropic from their point of confluence to the secondary choking location. Consequently, the condition that the static pressures be equal at the boundary between the primary and secondary streams is not satisfied.

A modified or quasi-one-dimensional model has also been applied to ejectors with short mixing tubes in which case the secondary and primary streams are assumed to remain distinct from entrance to exit [7].

Addy and Chow [8-11] developed a more sophisticated approach for the prediction of secondary stream choking within the mixing tube. In this model, the secondary stream was treated by the conventional methods of one-dimensional gas dynamics while the primary flow field was obtained from the two-dimensional method-of-characteristics for steady, irrotational, supersonic axisymmetric flows. This method allows the static pressures to be matched at the boundary of the streams since the primary stream may have a nonuniform pressure profile; although, the pressure must be uniform across the secondary stream. The simultaneous solution of the two flow fields satisfies the choking criteria, i.e., a Mach number of unity at the minimum flow area, was then corrected for viscous effects by superimposing the mixing layer on the inviscid boundary between the primary and secondary streams.

Howlett and Chow [12] added more detail to the Addy and Chow model using the method of integral relations for computation of the secondary stream but retaining the method-of-characteristics for the primary stream; the static pressure was matched at the boundary of the streams. The choking criteria for the secondary stream was developed based on a singularity in the integral relations describing the secondary flow.

Hill, et al. [13], applied the method of integral relations to both the secondary and primary streams but later [14,15] adopted a finite-difference model which does not attempt to separate the secondary and primary flows.

Each of the models discussed has its own particular advantages and disadvantages.

The one-dimensional model is well suited to broad-band parametric studies of ejector operation since:

1. It is computationally simple, each operating point being determined by the direct solution of a set of algebraic equations;
2. It applies equally well, at least in theory, to any constant-area ejector configurations; and
3. It is quite reliable as long as the assumption of one-dimensional or quasi-one-dimensional flow is satisfied.

The one-dimensional model has certain disadvantages in that:

1 It is restricted to the constant-area and constant-pressure ejectors where any pressure-area surface forces acting in the flow direction are eliminated from the momentum equation;
2. It may seriously error in flow regimes which are highly two-dimensional in nature;

3. It provides no insight into the actual flow phenomena; and
4. It requires some a priori knowledge of ejector operation to predict any limiting conditions such as choking of the secondary stream.

The method-of-characteristics, method of integral relations, and finite-difference models have all the advantages of sophistication in that:

1. They may be applied to all ejector configurations including variable-area geometries;
2. They provide field descriptions of increasing detail;
3. They satisfy the physical condition of continuity of static pressure across the boundary between the primary and secondary streams; and
4. They produce good results over all phases of ejector operation.

On the other hand, these models require:

1. Considerable knowledge, even empirical relations, taken from prior experimentation for their development; and
2. Significant amounts of computer time for program development and convergence problems which restricts their use for parametric studies.

1.2 STATEMENT OF THE PROBLEM

This theoretical and analytical analysis of the constant-area, supersonic-supersonic ejector was conducted to:

1. Develop a simplified mathematical model for predicting the operating characteristics of a constant-area, supersonic-supersonic ejector which is suitable for parametric evaluations and optimization procedures;

2. Provide quantitative and experimental data for verification of the theoretical model and identification of problem areas not indicated by the theoretical analysis; and

3. Compare the performance of the constant-area, supersonic-supersonic ejector with that of the constant-area, subsonic-supersonic ejector as applied to high-energy, chemical laser systems.

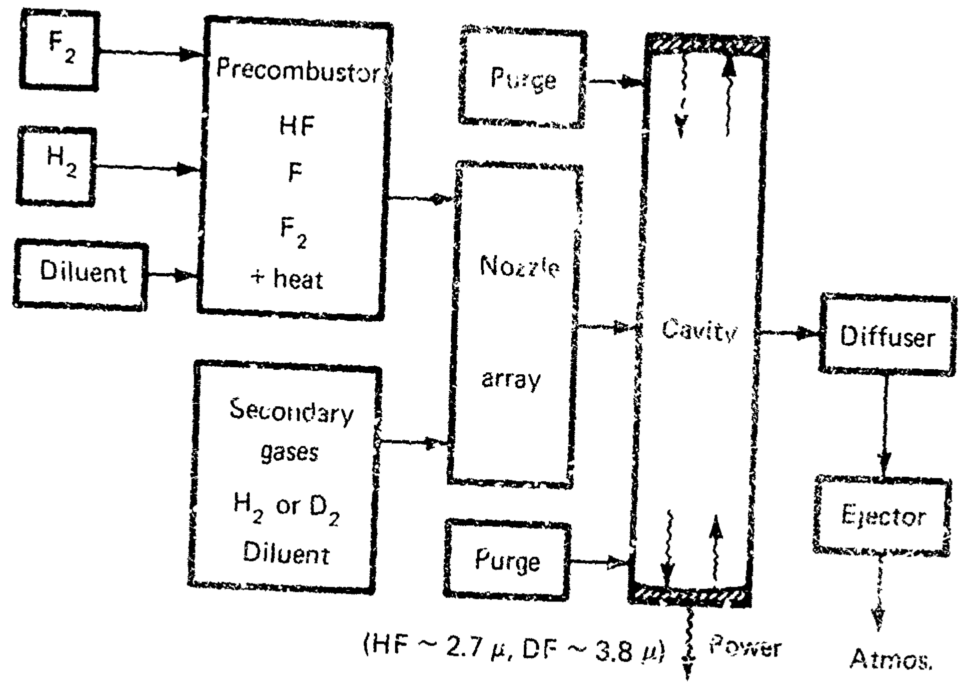


Figure 1.0-1 Typical Flow Diagram for a High-Energy, Chemical Laser System

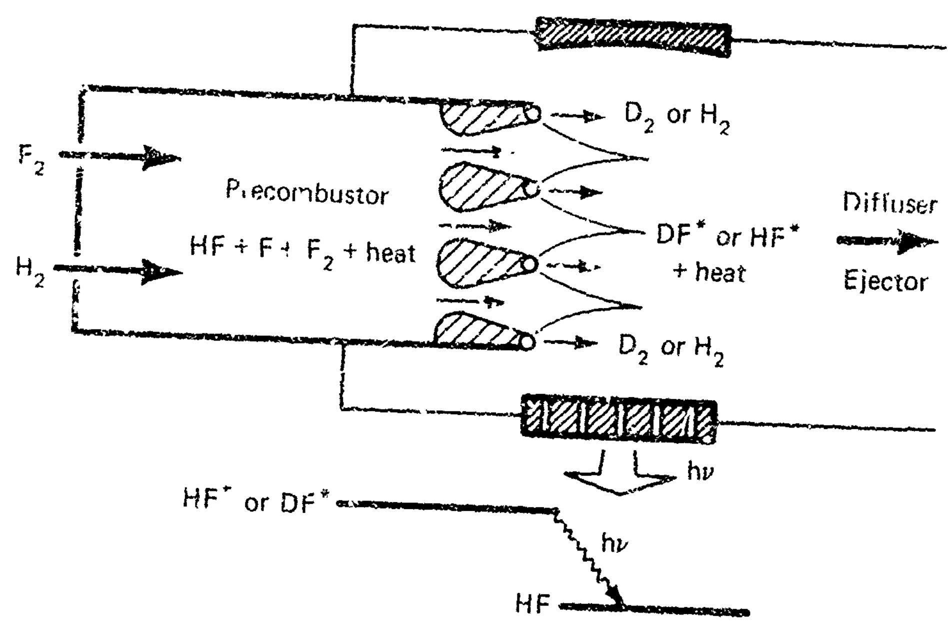


Figure 1.0-2 Laser Cavity Schematic

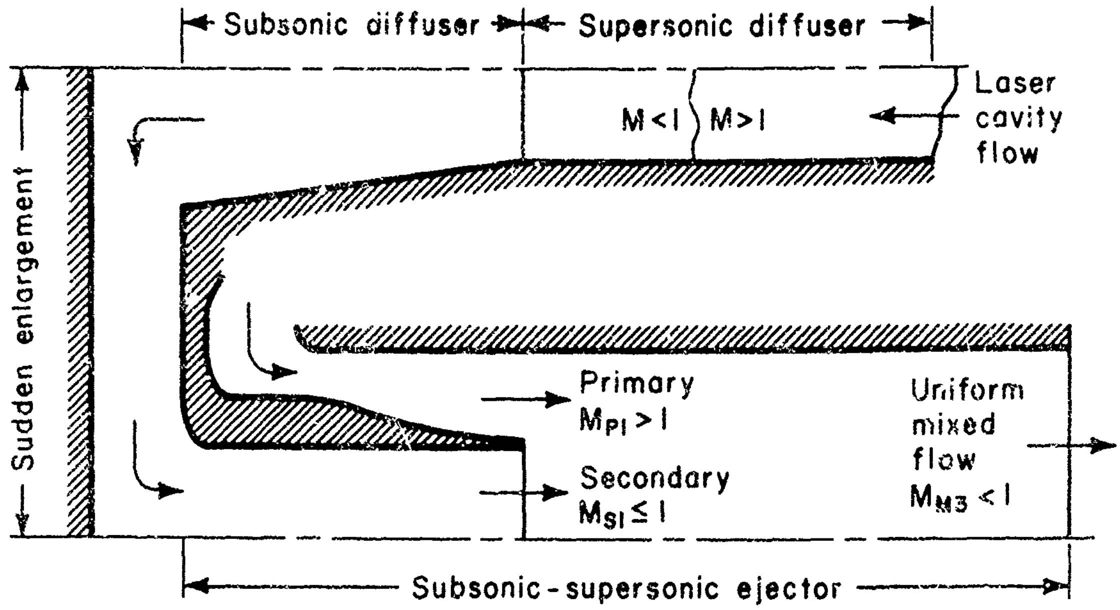


Figure 1.0-3 Subsonic-Supersonic Pumping System

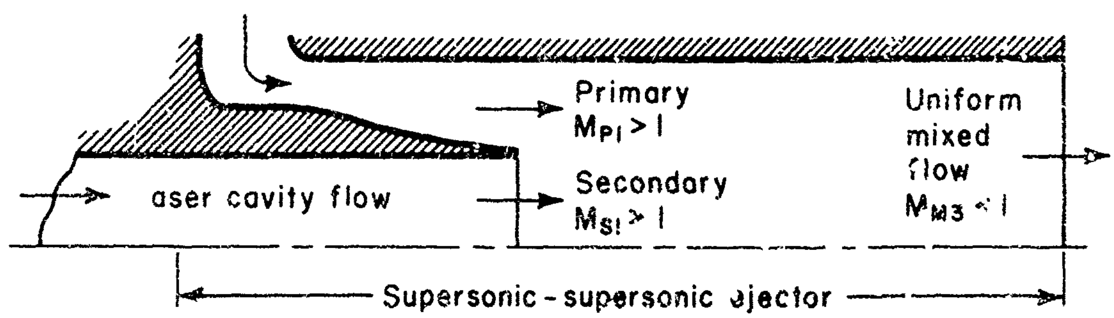


Figure 1.0-4 Supersonic-Supersonic Pumping System

2.0 THEORETICAL ANALYSIS OF THE CONSTANT-AREA, SUPERSONIC-SUPERSONIC EJECTOR

In the constant-area, supersonic-supersonic ejector of Fig. 2.0-1, the primary and secondary streams enter at supersonic Mach numbers where they begin to interact, mix, and diffuse. Proceeding through the ejector, these streams continue to mix and diffuse, thus approaching a uniform flow at the ejector exit. The result of this interaction, mixing, and diffusion process can be described by a one-dimensional, compressible flow model consisting of two components, an overall analysis of the constant-area mixing section, stations 1 to 3, and an analysis of the nearly inviscid interaction region just downstream of the confluence of the primary and secondary streams.

By tradition, the governing equations for subsonic-supersonic ejector models are nondimensionalized by the appropriate primary flow variables to allow for a zero secondary mass flow rate, and this tradition is maintained in the following analysis, however, in preference to people in the chemical laser field, the results are presented as nondimensionalized by the secondary flow variables.

2.1 ONE-DIMENSIONAL OVERALL MIXING SECTION ANALYSIS

By hypothesis, the streams entering the ejector must be supersonic. This criteria restricts the ejector operation to a plane as illustrated in Fig. 2.1-1, and prescribes the boundaries of this plane. So long as the entering streams remain supersonic, the ejector mass-flow ratio W_P/W_S is established independent of the ejector exit-plane pressure but directly proportional to the primary-to-secondary static pressure ratio P_{P1}/P_{S1} at the confluence point. The right-most boundary of the plane of operation

defines the maximum compression ratio and is determined by applying the conservation equations to the control volume of Fig. 2.1-2 together with the following assumptions:

(1) Steady flow, $\frac{\partial(\;)}{\partial t} \equiv 0$.

(2) Piecewise uniform flows at station 1 and uniform flow at station 3.

(3) The primary and secondary gases obey the perfect gas relationships.

(4) The primary and secondary streams mix ideally to form a mixed gas at station 3.

(5) Negligible wall shear stresses.

(6) Adiabatic flow between stations 1 and 3.

(7) No shaft or shear work between stations 1 and 3.

(8) Negligible body forces.

(9) The flow in the primary nozzle is isentropic from its stagnation state to the state at station 1.

The fundamental equations of continuity, momentum, in the flow direction, and energy are, respectively:

$$\frac{\partial}{\partial t}\int_{CV} \rho dv + \oint_{CS} \rho \bar{V} \cdot d\bar{A} = 0 \;, \qquad (2.1\text{-}1)$$

$$\overset{+}{\rightarrow} \sum F_x = \frac{\partial}{\partial t}\int_{CV} V_x(\rho dv) + \oint_{CS} V_x(\rho \bar{V} \cdot d\bar{A}) \;, \qquad (2.1\text{-}2)$$

$$\frac{\delta Q}{\delta t} - \frac{\delta W_{ss}}{\delta t} = \frac{\partial}{\partial t}\int_{CV}\left(u + \frac{V^2}{2} + gz + \cdots\right)(\rho dV)$$

$$+ \oint_{CS}\left(h + \frac{V^2}{2} + gz + \cdots\right)(\rho\overline{V} \cdot d\overline{A}) \quad . \tag{2.1-3}$$

Applying assumptions (1,2) to Eqn. (2.1-1) yields

$$-\rho_{S1}V_{S1}A_{S1} - \rho_{P1}V_{P1}A_{P1} + \rho_{M3}V_{M3}A_{M3} = 0 \ ,$$

or in terms of the mass flow rate $W = \rho AV$,

$$\frac{W_M}{W_P} = 1 + \frac{W_S}{W_P} \quad . \tag{2.1-4}$$

Applying assumptions (1,2,5) to Eqn. (2.1-2) gives

$$P_{S1}A_{S1} + P_{P1}A_{P1} - P_{M3}A_{M3} = - V_{S1}(\rho_{S1}V_{S1}A_{S1})$$

$$- V_{P1}(\rho_{P1}V_{P1}A_{P1}) + V_{M3}(\rho_{M3}V_{M3}A_{M3}) \ ,$$

or in terms of the Mach number,

$$P_{S1}A_{S1}(1 + \gamma_S M_{S1}^2) + P_{P1}A_{P1}(1 + \gamma_P M_{P1}^2) = P_{M3}A_{M3}(1 + \gamma_M M_{M3}^2) \quad .$$

Since $A_{S1} + A_{P1} = A_{M3}$ for a constant-area mixing tube, the result is

$$\frac{P_{M3}}{P_{P1}} = \frac{\frac{P_{S1}}{P_{P1}} \cdot \frac{A_{S1}}{A_{P1}} \cdot f_1(\gamma_S, M_{S1}) + f_1(\gamma_P, M_{P1})}{\left(1 + \frac{A_{S1}}{A_{P1}}\right) f_1(\gamma_M, M_{M3})} \tag{2.1-5}$$

where $f_1(\gamma, M) = 1 + \gamma M^2$. (2.1-6)

Equation (2.1-3) together with assumptions (1,2,6,7,8) yields

$$- \left(h_{S1} + \frac{V_{S1}^2}{2}\right)(\rho_{S1} V_{S1} A_{S1}) - \left(h_{P1} + \frac{V_{P1}^2}{2}\right)(\rho_{P1} V_{P1} A_{P1})$$

$$+ \left(h_{M3} + \frac{V_{M3}^2}{2}\right)(\rho_{M3} V_{M3} A_{M3}) = 0 ,$$

or in terms of the mass flow rate and stagnation enthalpy $h_0 = h + \frac{V^2}{2}$,

$$h_{S0} W_S + h_{P0} W_P = h_{M0} W_M .$$

But since $h_0 = C_P T_0$ + constant for an ideal gas, the result is

$$\frac{T_{M0}}{T_{P0}} \cdot \frac{W_M}{W_P} \cdot \frac{(C_P)_M}{(C_P)_P} = 1 + \frac{T_{S0}}{T_{P0}} \cdot \frac{W_S}{W_P} \cdot \frac{(C_P)_S}{(C_P)_P} . \qquad (2.1\text{-}7)$$

Using assumptions (3,4), the specific heats of the mixed flow are related to their primary and secondary stream counterparts by

$$W_M (C_P)_M = W_S (C_P)_S + W_P (C_P)_P , \qquad (2.1\text{-}8)$$

$$W_M (C_V)_M = W_S (C_V)_S + W_P (C_V)_P . \qquad (2.1\text{-}9)$$

Rearranging Eqn. (2.1-8) as

$$\frac{W_M}{W_P} \cdot \frac{(C_P)_M}{(C_P)_P} = 1 + \frac{W_S}{W_P} \cdot \frac{(C_P)_S}{(C_P)_P} ,$$

and noting that $C_P = \left(\frac{\gamma}{\gamma - 1}\right) \frac{R}{Mw}$ for a perfect gas, gives the useful relations

$$\frac{(C_p)_S}{(C_p)_P} = \frac{Mw_P}{Mw_S}\left(\frac{\gamma_S}{\gamma_S - 1}\right)\left(\frac{\gamma_P - 1}{\gamma_P}\right) , \qquad (2.1\text{-}10)$$

$$\frac{W_M}{W_P} \cdot \frac{(C_p)_M}{(C_p)_P} = 1 + \frac{W_S}{W_P} \cdot \frac{Mw_P}{Mw_S}\left(\frac{\gamma_S}{\gamma_S - 1}\right)\left(\frac{\gamma_P - 1}{\gamma_P}\right) . \qquad (2.1\text{-}11)$$

Similarly, rearranging Eqn. (2.1-9) as

$$\frac{W_M}{W_P} \cdot \frac{(C_V)_M}{(C_V)_P} = 1 + \frac{W_S}{W_P} \cdot \frac{(C_V)_S}{(C_V)_P}$$

and noting that $C_V = (\frac{1}{\gamma-1}) \frac{R}{Mw}$ for a perfect gas, gives the useful relations

$$\frac{(C_V)_S}{(C_V)_P} = \frac{Mw_P}{Mw_S}\left(\frac{\gamma_P - 1}{\gamma_S - 1}\right) , \qquad (2.1\text{-}12)$$

$$\frac{W_M}{W_P} \cdot \frac{(C_V)_M}{(C_V)_P} = 1 + \frac{W_S}{W_P} \cdot \frac{Mw_P}{Mw_S}\left(\frac{\gamma_P - 1}{\gamma_S - 1}\right) . \qquad (2.1\text{-}13)$$

The mass flow rate, W, is expressed in terms of the mass flow function by

$$\frac{W}{PA}\left[\frac{R}{Mw} \cdot T_0\right]^{1/2} = M\left\{\gamma\left[1 + \frac{(\gamma-1)}{2} M^2\right]\right\}^{1/2} \equiv f_2(\gamma,M) . \qquad (2.1\text{-}14)$$

Then using this relation, the secondary-to-primary mass flow ratio is related to the static pressure ratio at the confluence point by

$$\frac{W_S}{W_P} = \frac{P_{S1}}{P_{P1}} \cdot \frac{A_{S1}}{A_{P1}}\left[\frac{Mw_S}{Mw_P} \cdot \frac{T_{P0}}{T_{S0}}\right]^{1/2} \frac{f_2(\gamma_S,M_{S1})}{f_2(\gamma_P,M_{P1})} . \qquad (2.1\text{-}15)$$

Since $\gamma = \frac{C_P}{C_V}$ for a perfect gas, the mixed gas property is given by

$$\gamma_M = \frac{(C_P)_M}{(C_V)_M} = \frac{(C_P)_P}{(C_V)_P} \cdot \frac{\frac{W_M}{W_P} \cdot \frac{(C_P)_M}{(C_P)_P}}{\frac{W_M}{W_P} \cdot \frac{(C_V)_M}{(C_V)_P}} \; ,$$

which, with Eqns. (2.1-11) and (2.1-13), becomes

$$\gamma_M = \frac{\frac{W_S}{W_P} \cdot \frac{Mw_P}{Mw_S} \left(\frac{\gamma_S}{\gamma_S - 1}\right) + \left(\frac{\gamma_P}{\gamma_P - 1}\right)}{\frac{W_S}{W_P} \cdot \frac{Mw_P}{Mw_S} \left[\left(\frac{\gamma_S}{\gamma_S - 1}\right) - 1\right] + \left[\left(\frac{\gamma_P}{\gamma_P - 1}\right) - 1\right]} \; . \qquad (2.1\text{-}16)$$

Subtracting Eqn. (2.1-8) from Eqn. (2.1-9) and using the perfect gas relation $\frac{R}{Mw} = C_P - C_V$ yields

$$\frac{W_M}{W_P} \cdot \frac{Mw_P}{Mw_M} = 1 + \frac{W_S}{W_P} \cdot \frac{Mw_P}{Mw_S} \; .$$

Then applying Eqn. (2.1-4) and rearranging results in

$$\frac{Mw_M}{Mw_P} = \frac{\frac{W_S}{W_P} + 1}{\frac{W_S}{W_P} \cdot \frac{Mw_P}{Mw_S} + 1} \; . \qquad (2.1\text{-}17)$$

Substituting relations (2.1-10) and (2.1-11) into Eqn. (2.1-7) gives

$$\frac{T_{M0}}{T_{P0}} = \frac{\frac{T_{S0}}{T_{P0}} \cdot \frac{W_S}{W_P} \cdot \frac{Mw_P}{Mw_S} \left(\frac{\gamma_S}{\gamma_S - 1}\right) + \left(\frac{\gamma_P}{\gamma_P - 1}\right)}{\frac{W_S}{W_P} \cdot \frac{Mw_P}{Mw_S} \left(\frac{\gamma_S}{\gamma_S - 1}\right) + \left(\frac{\gamma_P}{\gamma_P - 1}\right)} \; . \qquad (2.1\text{-}18)$$

Using the mass flow function (2.1-14), the mixed-to-primary mass flow ratio is expressed as

$$\frac{W_M}{W_P} = \frac{P_{M3}}{P_{P1}} \cdot \frac{A_{M3}}{A_{P1}} \left[\frac{Mw_M}{Mw_P} \cdot \frac{T_{P0}}{T_{M0}}\right]^{1/2} \frac{f_2(\gamma_M, M_{M3})}{f_2(\gamma_P, M_{P1})} .$$

Applying Eqn. (2.1-4) and the relation $A_{S1} + A_{P1} = A_{M3}$, this equation becomes

$$\frac{P_{M3}}{P_{P1}} \left[1 + \frac{A_{S1}}{A_{P1}}\right] \left[\frac{Mw_M}{Mw_P} \cdot \frac{T_{P0}}{T_{M0}}\right]^{1/2} \frac{f_2(\gamma_M, M_{M3})}{f_2(\gamma_P, M_{P1})} = 1 + \frac{W_S}{W_P} .$$

Then eliminating $\frac{P_{M3}}{P_{P1}}$ with Eqn. (2.1-5) yields

$$f_3(\gamma_M, M_{M3}) = \frac{\left[\frac{Mw_M}{Mw_P} \cdot \frac{T_{P0}}{T_{M0}}\right]^{1/2} \left[\frac{P_{S1}}{P_{P1}} \cdot \frac{A_{S1}}{A_{P1}} \cdot f_1(\gamma_2, M_{S1}) + f_1(\gamma_P, M_{P1})\right]}{\left[1 + \frac{W_S}{W_P}\right] f_2(\gamma_P, M_{P1})} \qquad (2.1\text{-}19)$$

where

$$f_3(\gamma, M) \equiv \frac{f_1(\gamma, M)}{f_2(\gamma, M)} = \frac{1 + \gamma M^2}{M\{\gamma[1 + (\frac{\gamma-1}{2})M^2]\}^{1/2}} . \qquad (2.1\text{-}20)$$

The exit Mach number is obtained by solving the quadratic equation

$$\left[\frac{(\gamma_M - 1)}{2} f_3^2 - \gamma_M\right] (M_{M3}^2)^2 + [f_3^2 - 2] M_{M3}^2 - \left[\frac{1}{\gamma_M}\right] = 0 . \qquad (2.1\text{-}21)$$

Then the mixed-to-primary static pressure ratio is found by solving, in order:

(1) Equation (2.1-15) for $\frac{W_S}{W_P}$,

(2) Equation (2.1-16) for γ_M ,

(3) Equation (2.1-17) for $\frac{Mw_M}{Mw_P}$,

(4) Equation (2.1-18) for $\frac{T_{M0}}{T_{P0}}$,

(5) Equation (2.1-19) for $f_3(\gamma_M, M_{M3})$,

(6) Equation (2.1-21) for M_{M3}^2 , and

(7) Equation (2.1-5) for $\frac{P_{M3}}{P_{P1}}$,

where γ_S, γ_P, $\frac{Mw_S}{Mw_P}$, $\frac{T_{S0}}{T_{P0}}$, M_{S1}, M_{P1}, $\frac{A_{S1}}{A_{P1}}$, and $\frac{P_{S1}}{P_{P1}}$ are the independent variables or ejector parameters. For computational purposes, the static pressure P_{P1} may be obtained from the stagnation pressure P_{P0} using assumption (9) and the isentropic flow relation

$$\frac{P_0}{P}(\gamma, M) = [1 + (\frac{\gamma-1}{2}) M^2]^{\frac{\gamma}{\gamma-1}} . \qquad (2.1\text{-}22)$$

For chemical laser applications, relation (2.1-22) may not be applied to the secondary stream unless P_{S0} is taken at station 1 in Fig. 2.0-1 since the laser cavity flow will not be isentropic.

It should be noted that Eqn. (2.1-21) has two roots for M_{M3}^2 giving subsonic and supersonic values of M_{M3}. The right-most boundary of the plane of operation, Fig. 2.1-1, is calculated from the subsonic value of M_{M3}, whereas the supersonic value of M_{M3} divides the plane into supersonic solutions and subsonic solutions. It is also interesting to note that when supersonic solutions along the supersonic-subsonic dividing line are

diffused through a normal shock wave, they yield exactly the subsonic solutions along the right-most boundary of the plane. Of course, the ejector may operate anywhere within the boundaries of the plane of supersonic-supersonic operation; however, given W_P/W_S or P_{P0}/P_{S1}, the most desirable operation is at the right-most boundary since the potential exists for operation at this, the maximum compression ratio.

2.2 ONE-DIMENSIONAL ANALYSIS OF THE INVISCID INTERACTION REGION

The upper boundary of the plane of operation, Fig. 2.1-1, is also dictated by the requirement that both the secondary and primary streams remain supersonic. If the primary-to-secondary static pressure ratio at the confluence point is greater than 1 ($P_{P1}/P_{S1} > 1$), the secondary flow is compressed by the mutual interaction of the primary and secondary streams within the mixing tube. This process is limited, in a one-dimensional sense, to a "nearly" reversible recompression to sonic flow at the minimum area as determined by the control volumes shown in Fig. 2.2-1. Thus, the constant-area, supersonic-supersonic ejector couples the effect of an ideal aerodynamic, supersonic diffuser and momentum transfer through viscous mixing.

The control volume of Fig. 2.2-1(a) extends from station 1 to station 2. In addition to the assumptions listed in Section 2.1, the following additional assumptions are made:

(10) The streams remain distinct and do not mix between stations 1 and 2.

(11) The flow is isentropic for each stream between stations 1 and 2.

(12) The average pressures of the streams can be different at each cross-section; thus, continuity of static pressure at the boundary between the streams is not satisfied by this flow model.

(13) The Mach number of the secondary flow at station 2 is $M_{S2} = 1$.

(14) The static pressures are such that $P_{P1} > P_{S1}$.

For an isentropic, compressible flow, the area ratio, A/A^*, is expressed in terms of the area ratio function by

$$\frac{A}{A^*} = \frac{1}{M}\{(\frac{2}{\gamma+1})[1 + (\frac{\gamma-1}{2}) M^2]\}^{\frac{\gamma+1}{2(\gamma-1)}} \equiv f_4(\gamma,M) \quad . \qquad (2.2\text{-}1)$$

since $M_{S2} = 1$, $A_{S2} = A_S^*$, and for a constant-area mixing tube $A_{S1} + A_{P1} = A_{S2} + A_{P2}$. Then

$$\frac{A_{P2}}{A_P^*} = \frac{A_{P1}}{A_P^*}\{1 + \frac{A_{S1}}{A_{P1}}[1 - \frac{A_S^*}{A_{S1}}]\} \text{ , or}$$

$$\frac{A_{P2}}{A_P^*} = f_4(\gamma_P,M_{P1})\ \{1 + \frac{A_{S1}}{A_{P1}}[1 - (\frac{1}{f_4(\gamma_S,M_{S1})})]\} \quad ; \qquad (2.2\text{-}2)$$

and

$$f_4(\gamma_P,M_{P2}) = \frac{A_{P2}}{A_P^*} \qquad (2.2\text{-}3)$$

can be solved for the supersonic value of M_{P2}.

By assumptions (10,11), W_S, W_P, T_{S0}, and T_{P0} are constant from station 1 to station 2 in Fig. 2.2-1(a). Then the mass flow function (2.1-14) gives

$$\frac{P_{S2}}{P_{S1}} \cdot \frac{A_{S2}}{A_{S1}} = \frac{f_2(\gamma_S,M_{S1})}{f_2(\gamma_S,M_{S2})} \quad \text{, and} \qquad (2.2\text{-}4)$$

$$\frac{P_{P2}}{P_{P1}} \cdot \frac{A_{P2}}{A_{P1}} = \frac{f_2(\gamma_P,M_{P1})}{f_2(\gamma_P,M_{P2})} \quad . \qquad (2.2\text{-}5)$$

Applying the momentum equation (2.1-2) to the combined control volume of Fig. 2.2-1(b) together with assumptions (1,2,5,10) yields

$$P_{S1}A_{S1} + P_{P1}A_{P1} - P_{S2}A_{S2} - P_{P2}A_{P2} = - V_{S1}(\rho_{S1}V_{S1}A_{S1})$$

$$- V_{P1}(\rho_{P1}V_{P1}A_{P1}) + V_{S2}(\rho_{S2}V_{S2}A_{S2}) + V_{P2}(\rho_{P2}V_{P2}A_{P2}) ,$$

or in terms of the Mach number,

$$P_{S1}A_{S1}(1 + \gamma_S M_{S1}^2) + P_{P1}A_{P1}(1 + \gamma_P M_{P1}^2) =$$

$$P_{S2}A_{S2}(1 + \gamma_S M_{S2}^2) + P_{P2}A_{P2}(1 + \gamma_P M_{P2}^2) \quad .$$

Then using the function (2.1-6), the result is

$$\frac{P_{S1}}{P_{P1}} \cdot \frac{A_{S1}}{A_{P1}} \frac{f_1(\gamma_S,M_{S1})}{f_1(\gamma_P,M_{P1})} + 1 = \frac{P_{S2}}{P_{S1}} \cdot \frac{A_{S2}}{A_{S1}} \cdot \frac{P_{S1}}{P_{P1}} \cdot \frac{A_{S1}}{A_{P1}} \frac{f_1(\gamma_S,M_{S2})}{f_1(\gamma_P,M_{P1})}$$

$$+ \frac{P_{P2}}{P_{P1}} \cdot \frac{A_{P2}}{A_{P1}} \frac{f_1(\gamma_P,M_{P2})}{f_1(\gamma_P,M_{P1})} \quad . \tag{2.2-6}$$

Combining Eqns. (2.2-4), (2.2-5), and (2.2-6) with $M_{S2} = 1$ yields

$$\frac{P_{S1}}{P_{P1}} = \frac{f_2(\gamma_P,M_{P1}) \cdot f_3(\gamma_P,M_{P2}) - f_1(\gamma_P,M_{P1})}{\frac{A_{S1}}{A_{P1}} [f_1(\gamma_S,M_{S1}) - f_2(\gamma_S,M_{S1}) \cdot f_3(\gamma_S,1)]} \tag{2.2-7}$$

where $f_3(\gamma,M)$ is the function (2.1-20).

Then the static pressure ratio P_{S1}/P_{P1} for an isentropic recompression of the secondary stream to sonic conditions at station 2 is obtained by solving, in order:

(1) Equation (2.2-2) for $\frac{A_{P2}}{A_P^*}$,

(2) Equation (2.2-1) for $M_{P2} > 1$, and

(3) Equation (2.2-7) for $\frac{P_{S1}}{P_{P1}}$,

where γ_S, γ_P, M_{S1}, M_{P1}, and $\frac{A_{S1}}{A_{P1}}$ are the independent variables or ejector parameters; and P_{P1} may again be related to P_{P0} by the isentropic flow function (2.1-22).

2.3 PARAMETRIC RESULTS

The maximum compression ratio for a given supersonic-supersonic ejector configuration, i.e. given γ_S, γ_P, Mw_S/Mw_P, T_{S0}/T_{P0}, M_{S1}, M_{P1}, and A_{S1}/A_{P1}, is defined by the intersection of the upper boundary or "upper limit line" of the plane of operation as calculated from Section 2.2, and the right-most boundary of the plane as calculated from Section 2.1. This intersection point is termed the "upper limit point" or "ULP" in Fig. 2.1-1.

The static pressure ratio P_{P1}/P_{S1} may take on values less than 1; however, the roles of driver and driven streams are interchamged and the plane of operation, Fig. 2.1-1, would be reproduced with the primary and secondary subscripts interchanged. Then for practical purposes, the lower boundary of the plane of supersonic-supersonic operation was taken to be the "matched pressure line" where $P_{P1} = P_{S1}$. The intersection of the matched pressure line with the right-most boundary of the plane is termed the "matched pressure point" or "MPP" in Fig. 2.1-1.

The influence of the input variables, γ_S, γ_P, Mw_S/Mw_P, T_{S0}/T_{P0}, M_{S1}, M_{P1}, and A_{S1}/A_{P1}, on the plane of operation is illustrated in

Figs. 2.3-1 to 2.3-6. The procedure for producing each figure was to hold all the ejector parameters at constant values, save one, and to vary this parameter over a wide range. Rather than plot the resultant planes of operation, only the loci of upper limit and matched pressure points are given. The base values for the input variables were in all figures:

$\gamma_S = 1.40$, $Mw_S/Mw_P = 1.00$, $\gamma_P = 1.40$, $T_{S0}/T_{P0} = 1.00$,

$M_{S1} = 2.00$, $A_{S1}/A_{P1} = 2.00$, $M_{P1} = 4.00$,

while each point on the graphs represent valid solutions to the equations of Sections 2.1 and 2.2, the figures with γ_S, γ_P, and Mw_S/Mw_P as the abcissa may not represent physically realistic solutions except at the base value, indicated by the vertical dashed line, since only limited combinations of γ and Mw occur in nature. It should also be noted that the identical influence of Mw_S/Mw_P and T_{S0}/T_{P0} on the plane of operation, as shown in Fig. 2.3-3, is simply a coincidence of the choice of base values. The most significant information given by Figs. 2.3-1 to 2.3-6 is the slope of each curve at the base value or vertical dashed line, since this slope indicates the partial derivative of the dependent variable, P_{P0}/P_{S1}, W_P/W_S, or P_{ME}/P_{S1}, with respect to the independent variable.

2.4 COMPUTER PROGRAMS

The analyses of Sections 2.1 and 2.2 were the bases for the development of computer programs for analyzing the performance of constant-area, supersonic-supersonic ejectors. These programs along with sample input and output are presented in detail in APPENDICES 7.2 and 7.3 for programs CASSE and CASSEP, respectively.

These computer programs were used to calculate the parametric results presented in Section 2.3.

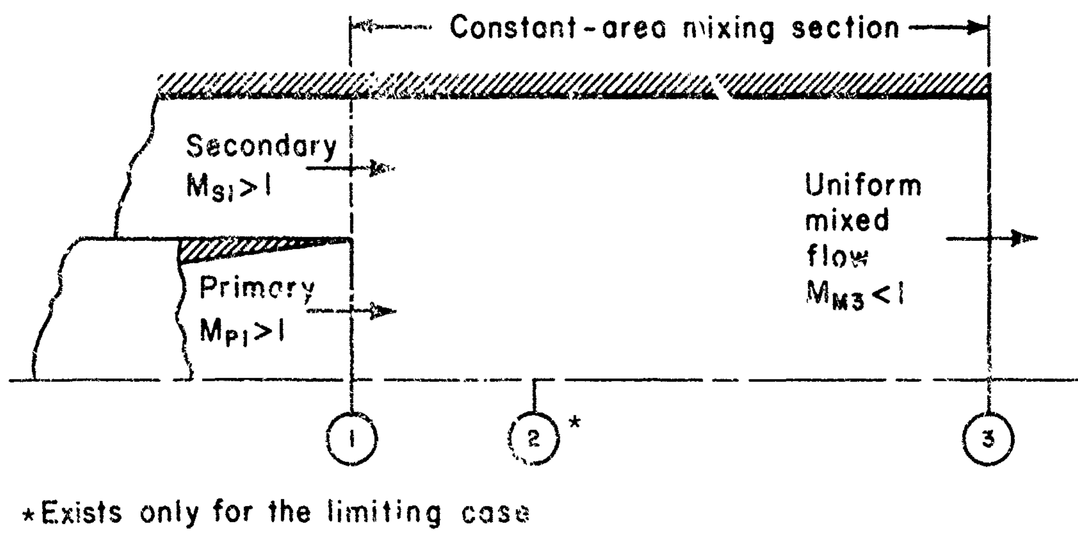


Figure 2.0-1 Constant-Area, Supersonic-Supersonic Ejector Configuration

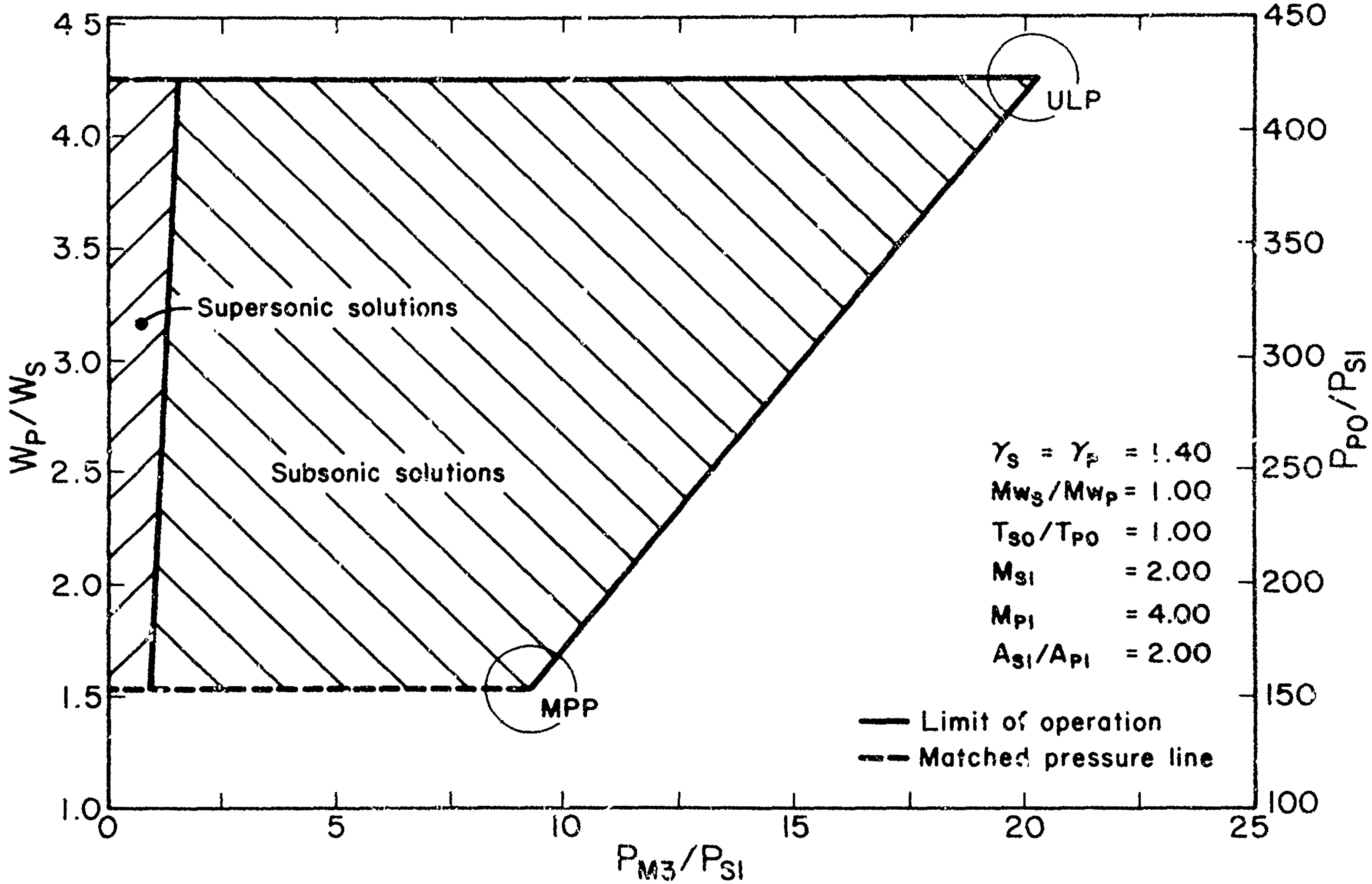
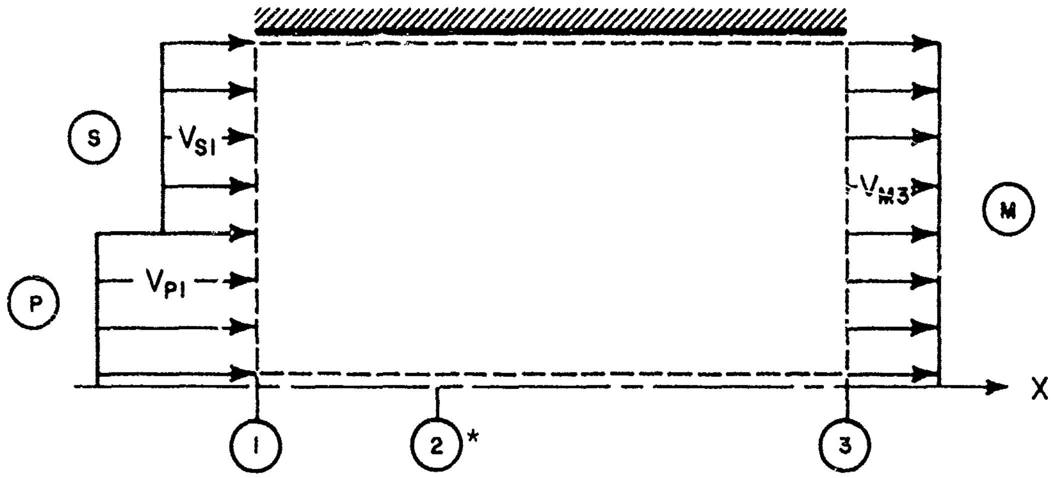


Figure 2.1-1 Typical Plane of Supersonic-Supersonic Operation

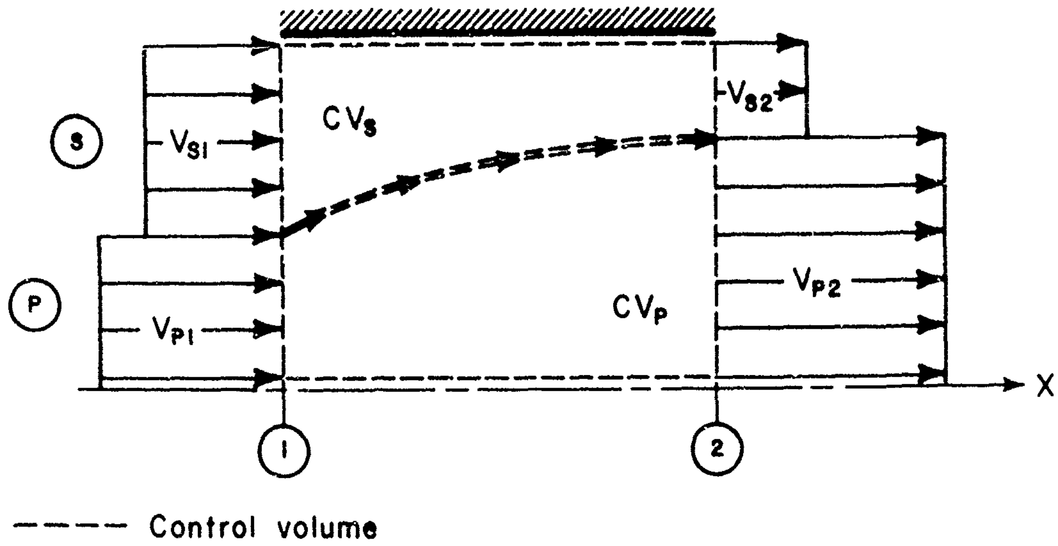


---- Control volume

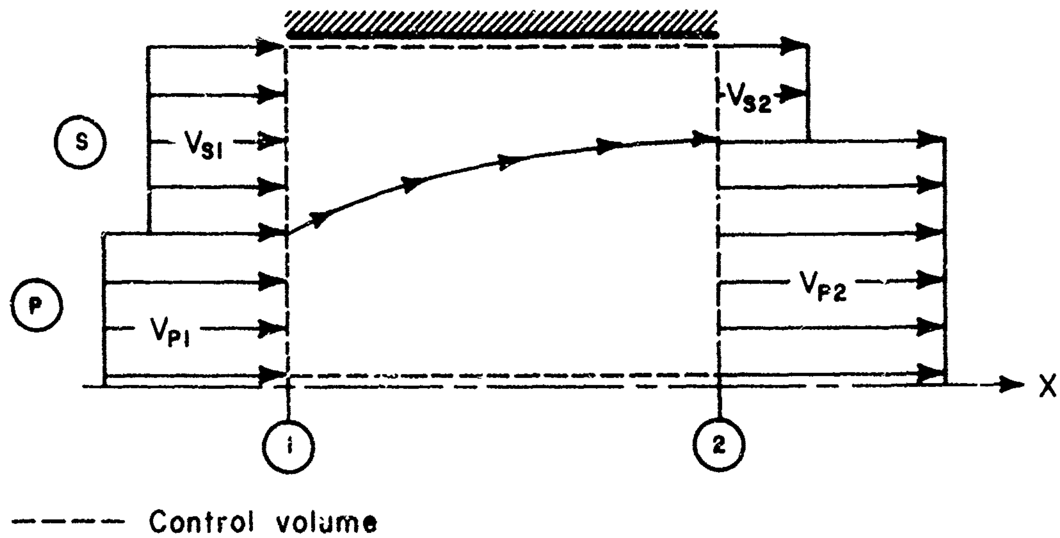
P, ρ, A, V, T, M, etc. are defined for each stream at sections 1 and 3.

* If the limiting condition exists

Figure 2.1-2 Constant-Area Mixing Section Control Volume



(a) Control Volume for the Distinct Streams



(b) Control Volume for the Combined Streams

Figure 2.2-1 Control Volumes for the Inviscid Interaction Region

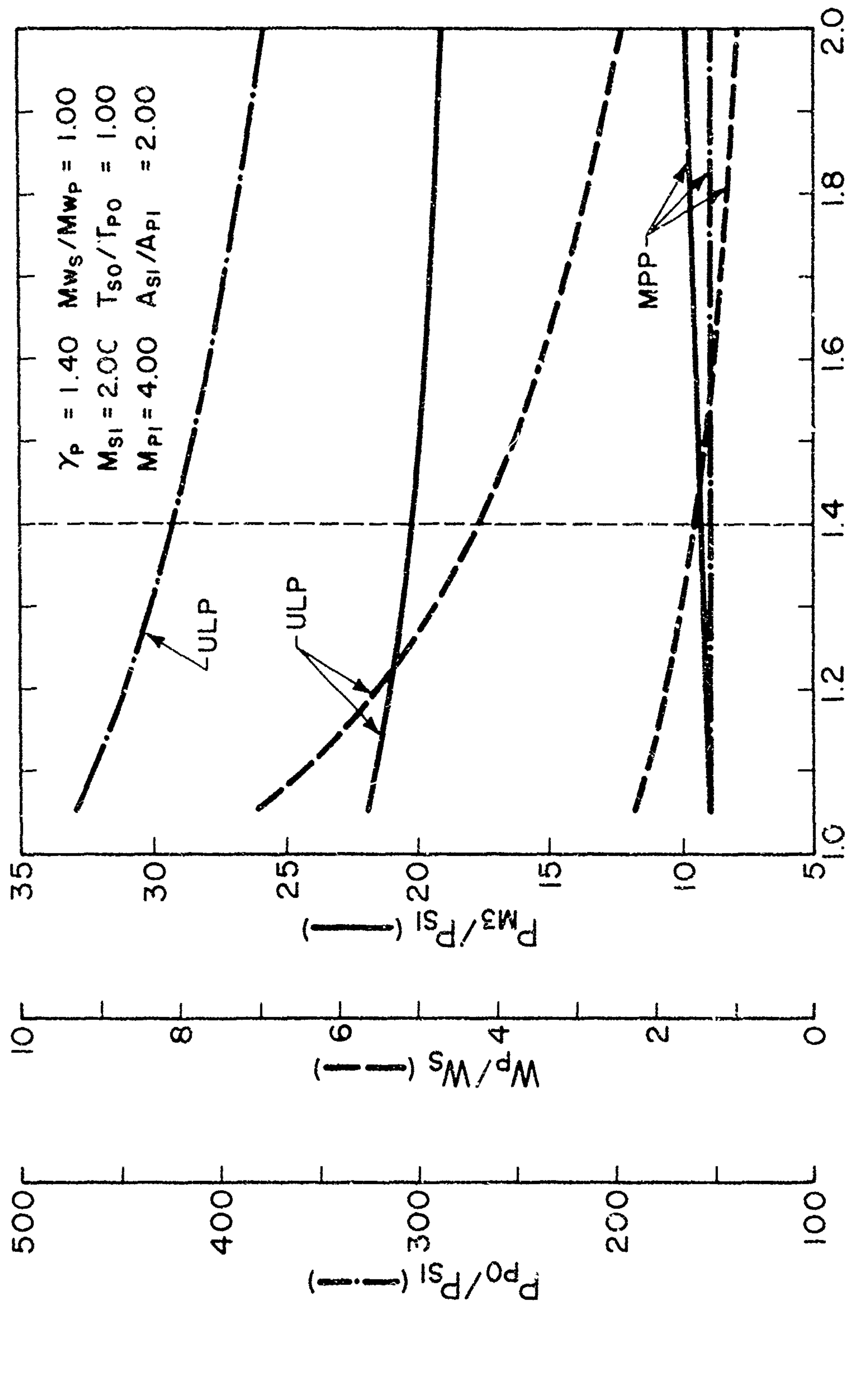


Figure 2.3-1 Influence of γ_s on the Plane of Supersonic-Supersonic Operation

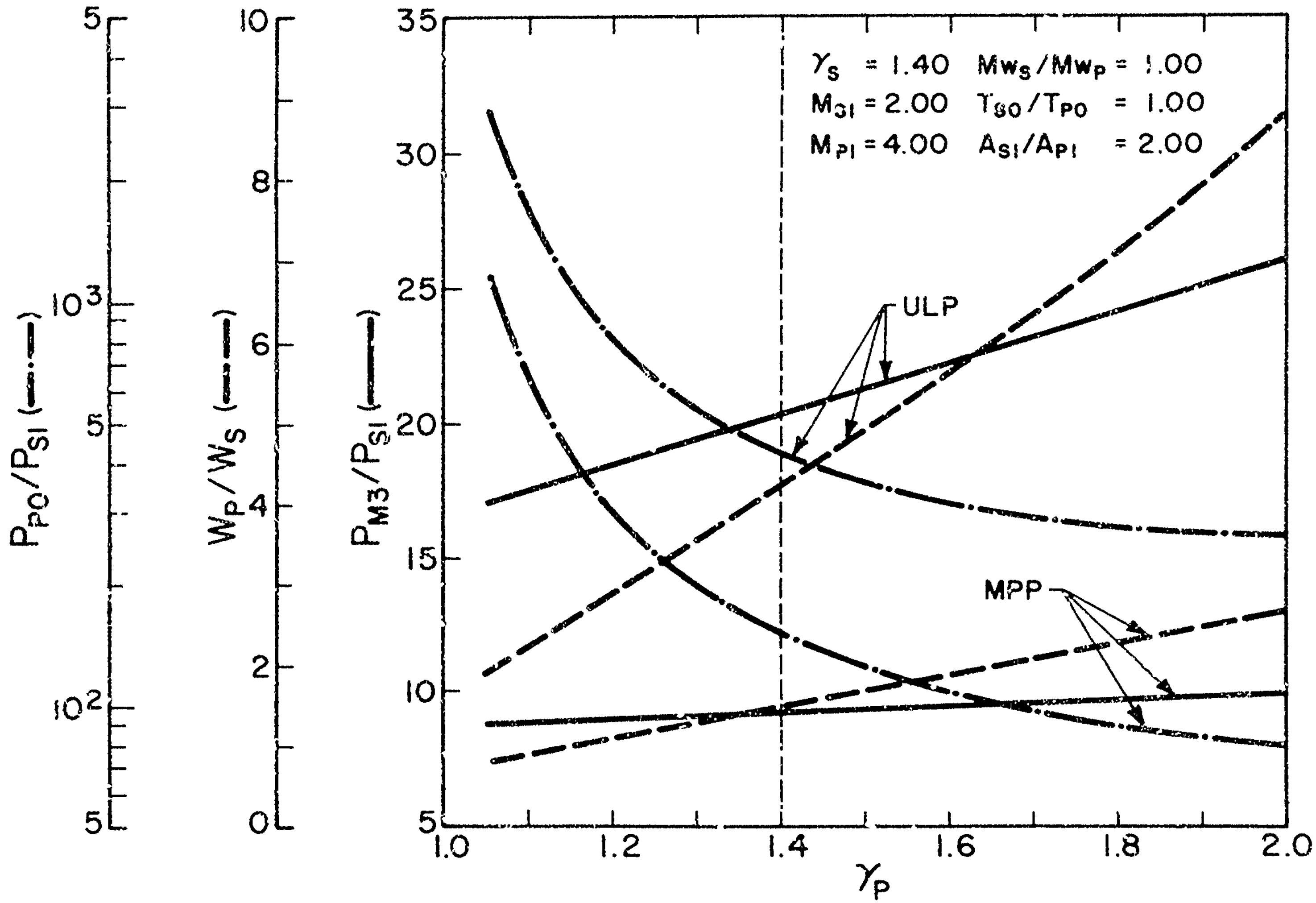


Figure 2.3-2 Influence of γ_P on the Plane of Supersonic-Supersonic Operation

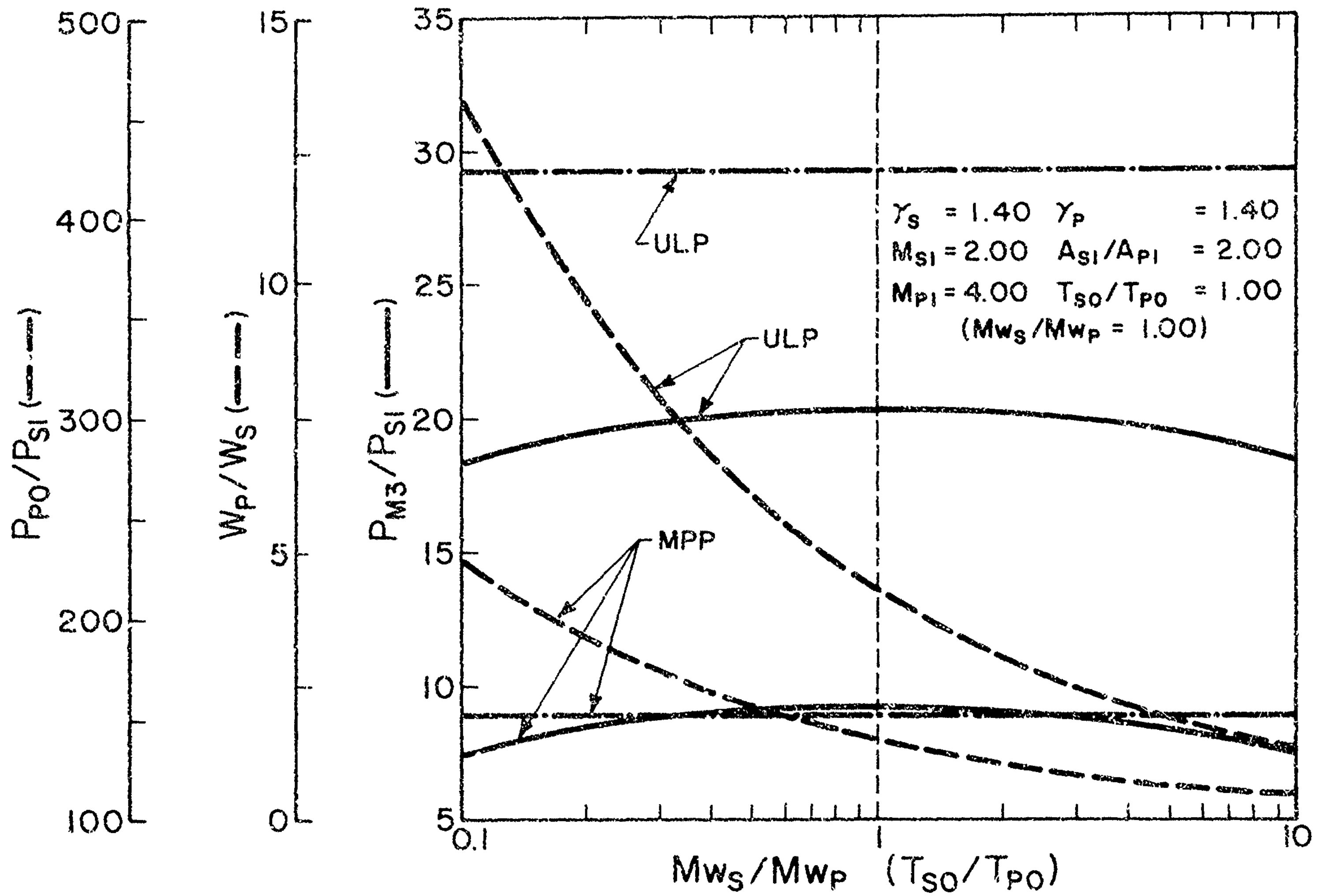


Figure 2.3-3 Influence of Mw_S/Mw_P and T_{SO}/T_{PO} on the Plane of Supersonic-Supersonic Operation

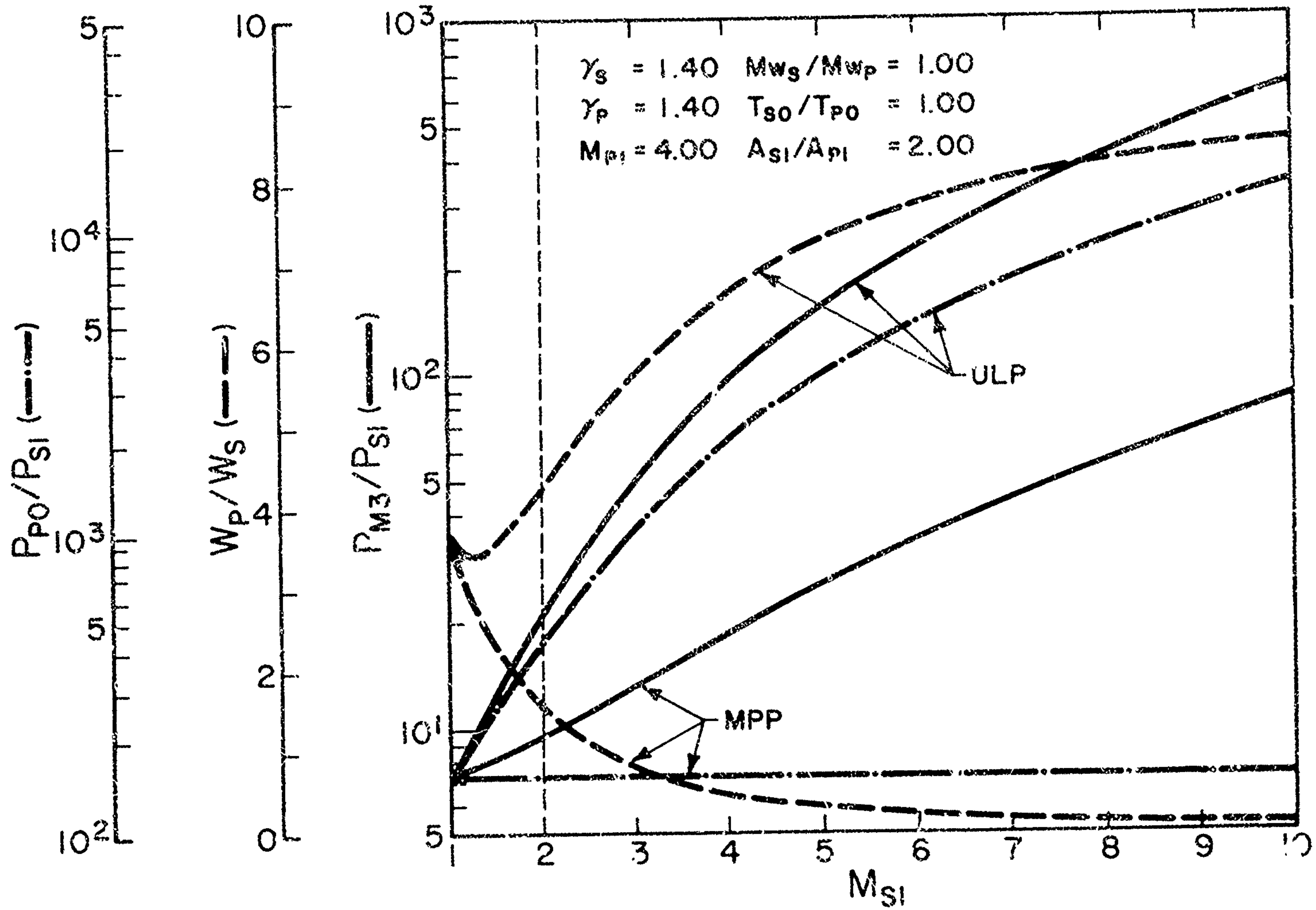


Figure 2.3-4 Influence of M_{S1} on the Plane of Supersonic-Supersonic Operation

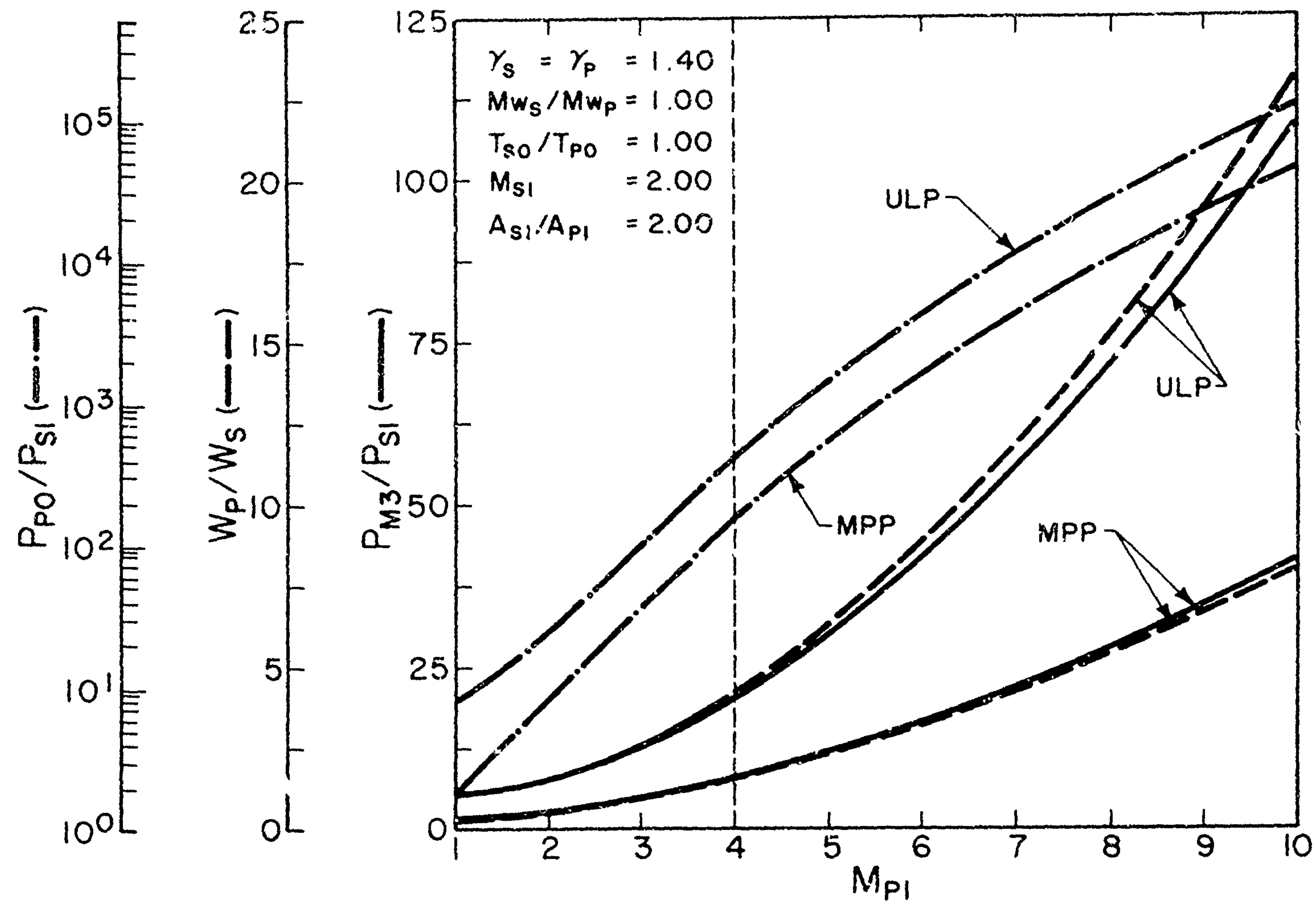


Figure 2.3-5 Influence of M_{P1} on the Plane of Supersonic-Supersonic Operation

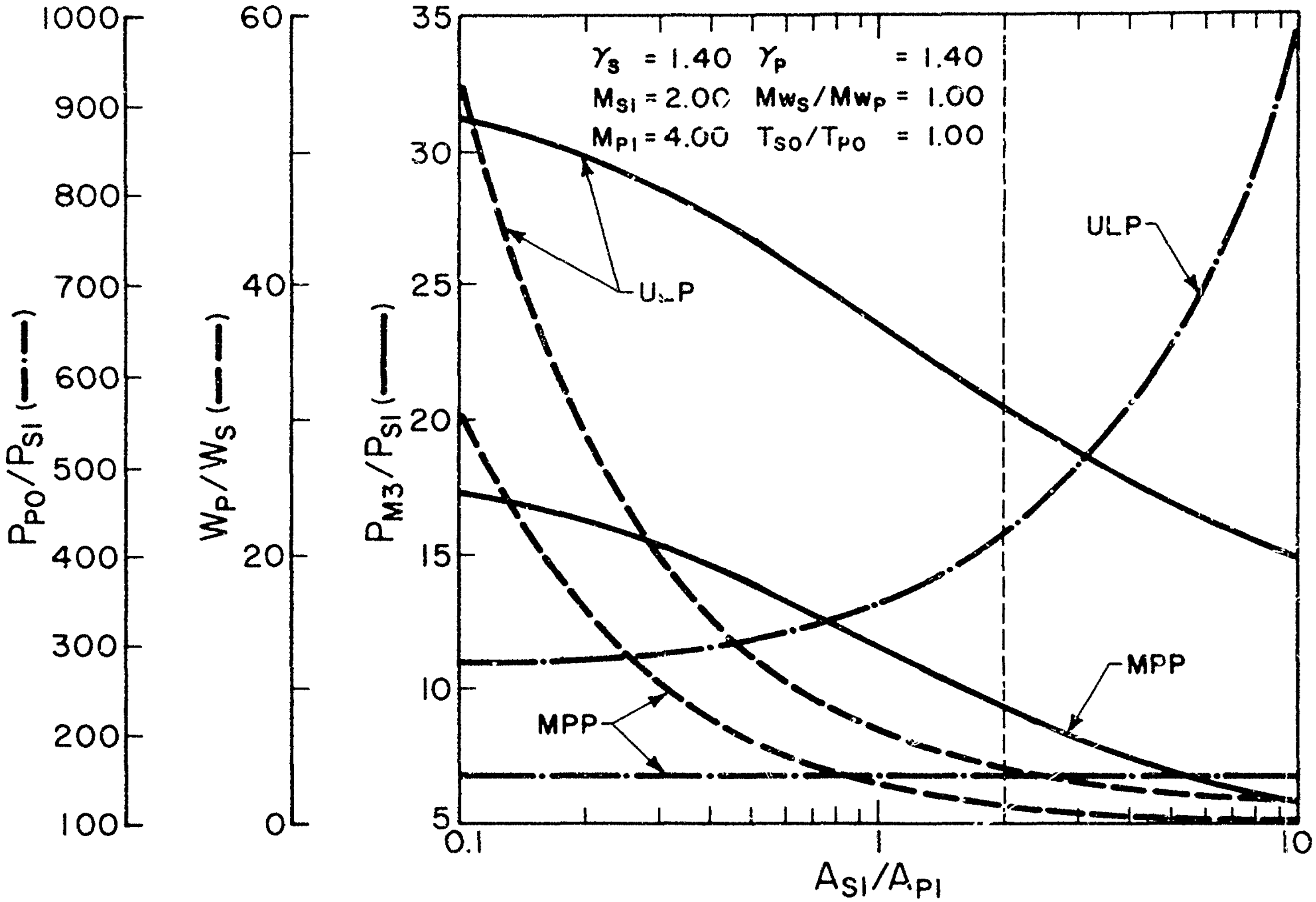


Figure 2.3-6 Influence of A_{S1}/A_{P1} on the Plane of Supersonic-Supersonic Operation

3.0 EXPERIMENTAL ANALYSIS OF THE CONSTANT-AREA, SUPERSONIC-SUPERSONIC EJECTOR

A series of small-scale, cold-flow, air-to-air ejector experiments were conducted to verify the theory of Section 2.0 and to provide a more detailed description of the flow field than necessarily allowed by a one-dimensional analysis.

3.1 EXPERIMENTAL APPARATUS

A half-section of the axisymmetric, supersonic-supersonic, ejector model is given in Fig. 3.1-1. This ejector model was designed and fabricated to facilitate a rapid replacement of nozzles and mixing tubes. Primary flow enters the ejector from a large stagnation chamber and is accelerated through an elliptical entrance section into the interchangeable nozzle. Secondary flow enters the secondary stagnation chamber from two sides and is accelerated between the nozzle wall and elliptical entrance section at the mixing tube base. Static pressure taps were installed along the mixing tube wall from the nozzle exit plane to the mixing tube exit at increments of one tube radius. A series of six static pressure taps, not shown, were equally spaced about the mixing tube axis at the nozzle exit plane to check the concentricity of the nozzle and mixing tube. In addition, five static pressure wall taps, not shown, were located upstream of the nozzle exit plane at increments of 2.54 mm to ensure that the entering secondary flow was supersonic.

For experimental purposes, the supersonic primary and secondary flows were produced by concentric nozzles of the continuous-slope type, as shown in Fig. 3.1-2. The primary stream was directed through the central nozzle, while the secondary flow was accelerated through the annular passage

formed by the outer nozzle wall and the constant-area mixing tube. Nozzle and mixing tube specifications are also given in Fig. 3.1-2 with the corresponding dimensionless parameters summarized in Table 3.1-1. While confined to an axisymmetric geometry and narrow Mach number range due to test facility limitations, these experimental configurations should be adequate for an initial evaluation of supersonic-supersonic ejector performance.

The continuous-slope nozzles constructed for these experiments were designed by the method-of-characteristics to produce uniform velocity and pressure distributions at the confluence of the secondary and primary streams, thus satisfying, at least ideally, the assumptions for the one-dimensional theory of Section 2.0. A photographic enlargement of one of these nozzles emphasizing the secondary or outer nozzle wall profile is presented in Fig. 3.1-3. As a design simplification, all four nozzles were machined to the same length which necessitated the addition of constant-area sections at the nozzle throat and exit segments as specified

Table 3.1-1 Dimensionless Parameters for the Experimental, Supersonic-Supersonic Ejector Model

	M_{P1}	M_{S1}	A_{S1}/A_{P1}
1	2.50	1.50	1.95
2	2.50	1.75	1.95
3	2.50	2.00	0.88
4	2.50	2.50	0.88

in Fig. 3.1-4. Although these constant-area sections would have no effect for a truly inviscid flow, they would promote boundary layer growth under actual experimental conditions. Figure 3.1-5 is a near actual size photograph of all four supersonic-supersonic nozzles showing their similarity in size and shape.

Photographs of the ejector components are given in Fig. 3.1-6 showing both front and rear views of the secondary stagnation chamber. It should be noted from Fig. 3.1-2 that the two constant-area mixing tubes are 10 tube diameters in length and that the interchangeable nozzles were constructed with a separate elliptical entrance section. A view of the ejector model in a partially assembled state is given in Fig. 3.1-7 showing the position of the supersonic-supersonic nozzle in the secondary stagnation chamber, one of two side entrance ports for the secondary flow, and one of two "U"-shaped baffles, the visible one surrounding the secondary stagnation pressure tap, which prevent the formation of a large circular vortex about the nozzle axis. All the ejector components were precision machined to design specifications with less than 1.27 mm clearance and O-ring seals at all the mating surfaces to ensure proper alignment and sealing.

Figure 3.1-8 is a flow diagram for the experimental program. Air from a common supply branched to two automatic control valves which maintained a constant stagnation pressure in the primary and secondary chambers. The air then passed through standard VDI nozzles for measurement of the primary and secondary mass flow rates. A final stagnation chamber was located at the mixing tube exit immediately upstream of a back pressure control valve to prevent local disturbances at this valve

from influencing the velocity and pressure distributions of the mixed, subsonic flow at the tube exit. The back pressure control valve was a sliding block arrangement with two blocks closing symmetrically across the exit duct.

Figure 3.1-9 is a photograph of the small-scale, ejector model installed on the test chamber, which served as the primary stagnation chamber, with a balance handle for manual adjustment of the back pressure control valve visible in the upper portion of the photo. Also visible are the pressure lines leading to the mixing tube wall taps and a portion of the silencer which supports the final stagnation chamber and back pressure control valve. For one experiment, a traversing pitot probe, as shown in Fig. 3.1-10, was added between the mixing tube and final stagnation chamber for measurement of the exit Mach number distribution.

3.2 EXPERIMENTAL PROCEDURE

The experimental, supersonic-supersonic ejector model was installed on a test chamber of the continuous flow facility in the Mechanical Engineering Laboratory and was operated with dry, compressed air. The tests were run at secondary stagnation pressures of 98 to 270 kPa absolute, primary stagnation pressures of 269 to 741 kPa absolute, and stagnation temperatures of approximately 294 K. The primary nozzle Reynolds number, based on the throat diameter, varied from 4.3×10^5 at $P_{P0} = 269$ kPa to 1.2×10^6 at $P_{P0} = 741$ kPa. Secondary nozzle throat Reynolds numbers are indicated in the experimental results.

Pressure data were taken from Bourdon-tube gauges and manometers or with a strain gauge transducer-digital counter system. The primary and secondary stagnation pressures and static pressures upstream of the

standard VDI nozzles were measured with Bourdon-tube gauges except at levels near atmospheric pressure, in which case a mercury manometer was used. Pressure differences across the standard VDI nozzles were measured with either mercury, Meriam 3†, or water filled U-tube manometers, depending on the magnitude of the pressure difference. Photographic records of all static pressures along the mixing tube wall were taken from mercury manometer boards. Stagnation pressure readings for the traversing pitot probe were taken with the strain gauge transducer-digital counter system.

Although six static pressure taps were available for the measurement of P_{S1}, only one was used in each experiment, and this pressure was read with both a mercury manometer and a strain gauge transducer. An attempt was made to measure an average value of P_{S1} by manifolding all six pressure taps; however, the resultant readings were lower than for any one given pressure tap.

Since the stagnation temperatures T_{P0} and T_{S0} are primarily dependent on the supply temperature, the primary stagnation temperature was measured with a dial thermometer and values for T_{S0} and the temperature of the air upstream of the standard VDI nozzles were assumed to equal this value for T_{P0}.

Maximum compression ratio data for each experimental ejector configuration were obtained in the following manner. With the back pressure control valve fully open, the secondary stagnation pressure P_{S0} was set at a fixed value to be maintained by the secondary automatic controller (see Fig. 3.1-8). The automatic controller for the primary stagnation

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†Product of the Meriam Instrument Company, Cleveland, Ohio.

pressure P_{P0} was then set at a fixed value such that the static pressure ratio P_{P1}/P_{S1} would lie, at least theoretically, in the range between the matched pressure and upper limit lines. The back pressure valve was then closed until the value of P_{S1}, as indicated by the digital counter, began to rise, at which point the mercury manometer board was photographed. This process was repeated for different combinations of P_{S0} and P_{P0} until the full range of P_{P1}/P_{S1} was covered unless otherwise restricted by the maximum supply pressure.

While the above process is necessarily transient in nature, the results are thought to be good since the point at which P_{S1} begins to rise rapidly, indicating a transition from supersonic to subsonic flow, was quite well defined and the time constant for the mercury manometer boards is much greater than for the strain gauge transducer-digital counter system. Thus, measurements of P_{S1} and P_{M3} from the mercury manometers should be very close to the limit of supersonic-supersonic operation. This thought is also supported on the basis of data repeatability which was about $\pm$ 1% for P_{M3}/P_{S1} with M_{S1} = 1.50.

Traverses with the pitot probe at the mixing tube exit could not be completed at exactly maximum back pressure conditions. The above procedure was followed until P_{S1} began to rise, and then the back pressure valve was opened slightly to reach a stable state for the traverse.

3.3 EXPERIMENTAL RESULTS

Maximum compression characteristics for the experimental, constant-area, supersonic-supersonic ejector configurations listed in Table 3.1-1 are presented in Figs. 3.3-1 to 3.3-4. In each figure, the data points are plotted on the plane of supersonic-supersonic operation as predicted

by the one-dimensional analysis of Section 2.0 and illustrated in Fig. 2.1-1. These data points indicate the maximum compression ratio, P_{M3}/P_{S1}, for subsonic values of M_{M3} and, therefore, should lie on the right-most boundary of the plane of supersonic-supersonic operation. Also, given the compression ratio P_{M3}/P_{S1}, the mass flow ratio data points should lie on the pressure ratio data points, i.e. the triangles should lie on the circles directly below them, since W_p/W_S is theoretically proportional to P_{P0}/P_{S1}. In all cases, given P_{P0}/P_{S1}, the experimental values for the maximum compression ratio P_{M3}/P_{S1} were 15 to 18 percent less than the theoretical, except for $M_{S1} = 1.50$, in which case the error was 21 to 22 percent, and the experimental values of W_p/W_S were 0 to 44 percent greater than the theoretical. It should also be noted that the percent errors in P_{M3}/P_{S1} and especially W_p/W_S increase with a decrease in the secondary nozzle throat Reynolds number as defined by

$$Re_{ST} = \frac{\rho V}{\mu} (D_{M3} - D_S^*) \quad .$$

Wall pressure distributions at maximum compression conditions for the ejector configurations listed in Table 3.1-1 are given in Figs. 3.3-5 to 3.3-8. Three pressure distributions are plotted in each figure which correspond to data points near the matched pressure point, upper limit point, and at some point midway between in Figs. 3.3-1 to 3.3-4.

At the matched pressure point, the wall pressure is initially constant followed by a near linear rise which levels off at the mixing tube exit. The linear rise covers a smaller portion of the mixing tube at the larger values of M_{S1} corresponding to the higher initial velocity of the

secondary stream and the fact that viscous mixing of the primary and secondary streams is accomplished in a shorter length as M_{S1} approaches M_{P1}.

At the upper limit point, the secondary stream undergoes a large initial recompression followed by a near linear rise which again levels off at the mixing tube exit. The initial pressure rise can be attributed to the aerodynamic diffuser formed by the primary stream as it expands into the mixing tube. As noted for the matched pressure data, the linear portion of the pressure rise occupies a smaller segment of the mixing tube as M_{S1} approaches M_{P1}, though the total pressure rise is much greater since more energy is transferred to the secondary stream as P_{P0}/P_{S1} is increased.

The wall pressure distributions of Figs. 3.1-5 to 3.1-8 also show that the low experimental values for the maximum compression ratio in Figs. 3.1-1 to 3.1-4 may be due, in part, to the mixing tube length which was equal to 10 tube diameters in all the experimental ejector configurations, 8 to 12 tube diameters being sufficient for most subsonic-supersonic ejectors. If the mixing tube is long enough for completion of the viscous mixing process, yet not too long such that wall friction becomes important, then the wall pressure distributions should exhibit a near linear rise which levels off to a constant value as the primary and secondary streams mix to a uniform flow. With the exception of Fig. 3.3-8, where $M_{S1} = M_{P1}$, it appears that the linear portion of the wall pressure distributions end at the mixing tube exit, that the viscous mixing and diffusion process may not have been completed, and that the compression ratio might be increased with a longer mixing tube. This conclusion is,

moreover, supported by the exit Mach number distributions at maximum compression conditions in Fig. 3.3-9 which show that for $M_{S1} = 2.00$, the potential exists for further mixing and diffusion even for P_{P1}/P_{S1} near the matched pressure line.†

The large percent errors in W_P/W_S and the changes in compression characteristics with Re_{ST} noted in Figs. 3.3-1 to 3.3-4 are probably due to separation of the secondary flow upstream of the confluence point. In the one-dimensional theory of Section 2.0, it is assumed that the secondary stream would undergo an isentropic recompression to, at the least, sonic conditions for $P_{P1} \leq P_{S1}$ as shown schematically in Fig. 3.3-10(a). In the real situation, however, the secondary stream may not be able to change directions at station 1 without separating the boundary layer as illustrated in Fig. 3.3-10(b). The flow losses through the oblique shock structure may not be significant even with secondary separation, but the area A_{S1} is effectively reduced with a corresponding increase in P_{S1} and decrease in M_{S1}; hence, larger secondary stagnation pressures and mass flow rates are required to obtain the desired values of P_{P0}/P_{S1}. The region of secondary separation should grow with increasing values of P_{P1}/P_{S1} and decreasing secondary Reynolds number, and this fact is evident in Fig. 3.3-11 where M_{S1}, as calculated from the isentropic flow function $\frac{P}{P_0}\frac{A}{A^*}(\gamma, M)$, is plotted versus P_{P0}/P_{S1} for the experimental data of Figs. 3.3-1 to 3.3-4. Some methods, such as Zukoski's [16] are available for description of the separation region, but prediction of the static pressure ratio P_{P1}/P_{S1} at the actual onset of separation requires empirical data, thus defeating most simple models for parametric evaluation of supersonic-supersonic ejector performance.

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†The results of an experimental investigation of a typical ejector configuration for variations in length-to-diameter ratio(L/D = 5, 7.5, 10, 12.5, 15) are presented in APPENDIX 7.6.

Near the matched pressure point, separation should not be a problem and the mass flow ratio data (triangles) of Figs. 3.3-1 to 3.3-4 should lie on the pressure data (circles). For M_{s1} = 1.75 and 2.50, this is indeed true; but for M_{s1} = 1.50 and 2.00, there is a small deviation. This deviation is apparently due to boundary layer growth in these two nozzles caused by the constant-area, exit segments which were added to the secondary nozzle contours as specified in Fig. 3.1-4.

As mentioned previously, the one-dimensional theory of Section 2.0 employed an isentropic recompression model for prediction of the upper limit to the plane of supersonic-supersonic operation. In Fig. 3.3-12, the wall pressure distributions near the upper limit point in Figs. 3.3-5 to 3.3-8 have been replotted with P_{s0} as the characteristic pressure in order to compress the scale. The initial recompression of the secondary stream to Mach numbers probably less than 1 ($P(x)/P_{s0} < 0.5283$) as shown in Fig. 3.3-12 suggests another simple model, a "two shock model" as illustrated in Fig. 3.3-13, which is also suitable for a one-dimensional analysis and, in addition, accounts for the irreversibilities in two oblique shocks. Of course, this model does not allow for secondary flow separation, nor would it apply to large turning angles where the two oblique shocks are replaced by a single, normal shock wave.

An attempt was made to compare the one-dimensional theory of Section 2.0 with the extensive supersonic wind tunnel-injector data of Hasel and Sinclair [4]. Unfortunately, these investigators did not measure the secondary stagnation pressure P_{s0} or include the static pressure P_{s1} at the injector, which makes any comparison impossible.

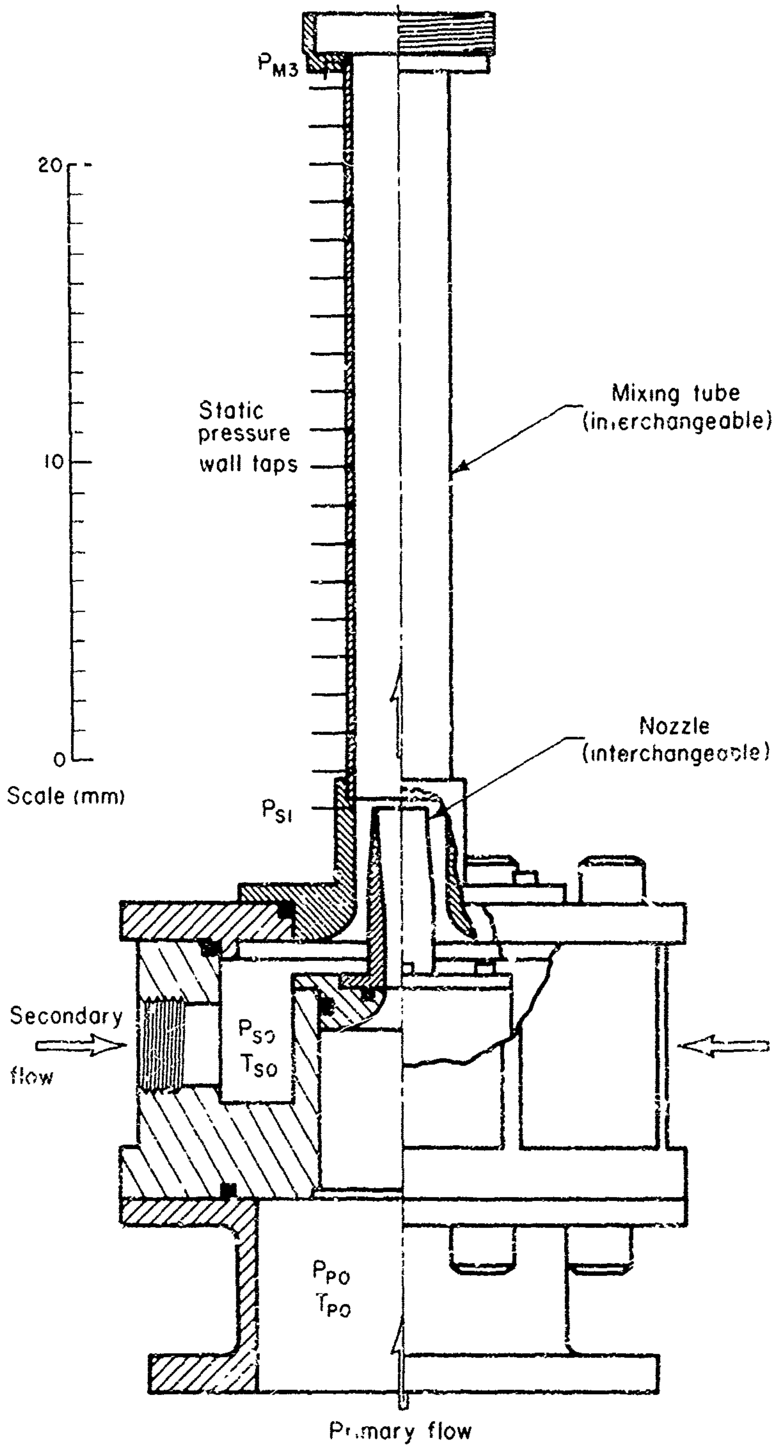
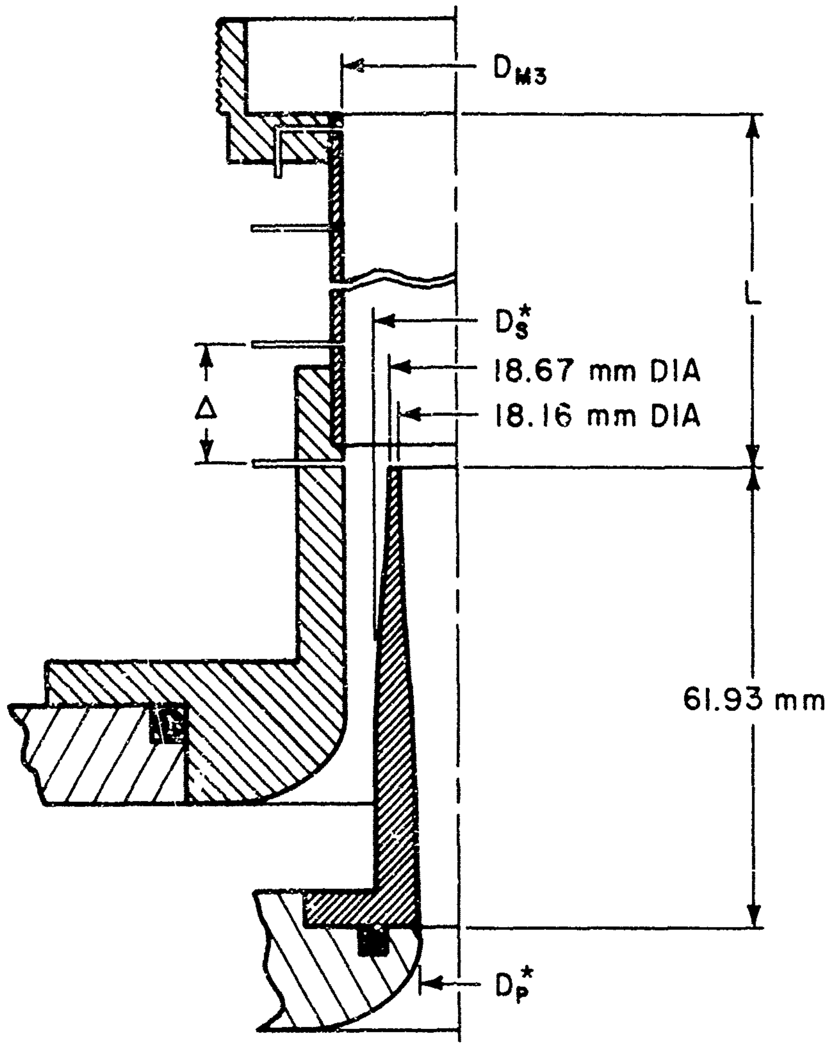


Figure 3.1-1 Half-Section of the Axisymmetric, Supersonic-Supersonic Ejector Model



	Nozzle				Mixing tube		
	M_{P1}	D_P^* (mm)	M_{S1}	D_S^* (mm)	D_{M3}(mm)	L (mm)	Δ (mm)
1	2.50	11.18	1.50	21.13	31.62	316.2	15.81
2	2.50	11.18	1.75	23.01	31.62	316.2	15.81
3	2.50	11.18	2.00	21.59	25.27	252.7	12.64
4	2.50	11.18	2.50	22.99	25.27	252.7	12.64

Figure 3.1-2 Section View and Specifications of the Continuous-Slope Nozzle and Constant-Area Mixing Tube Configurations

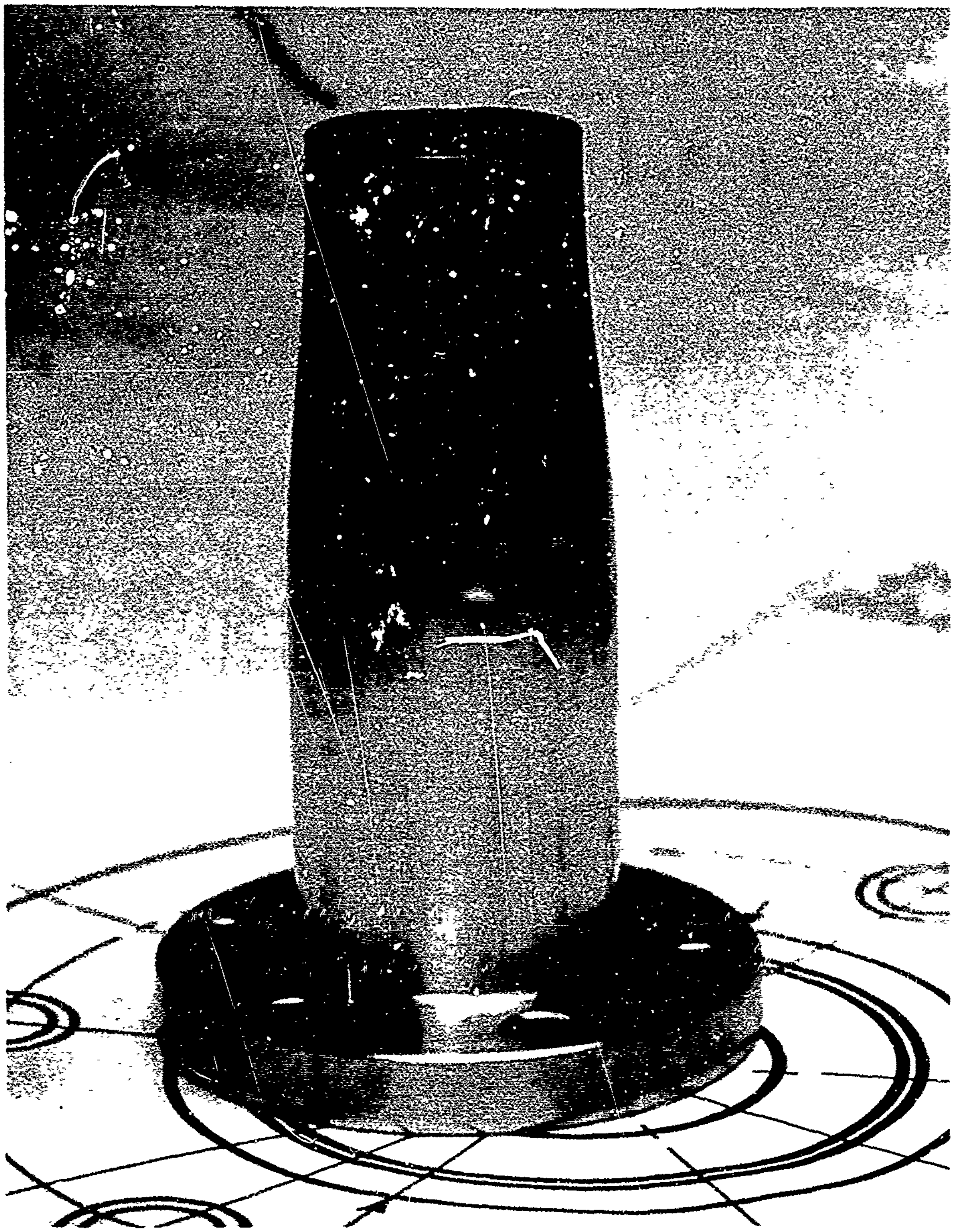
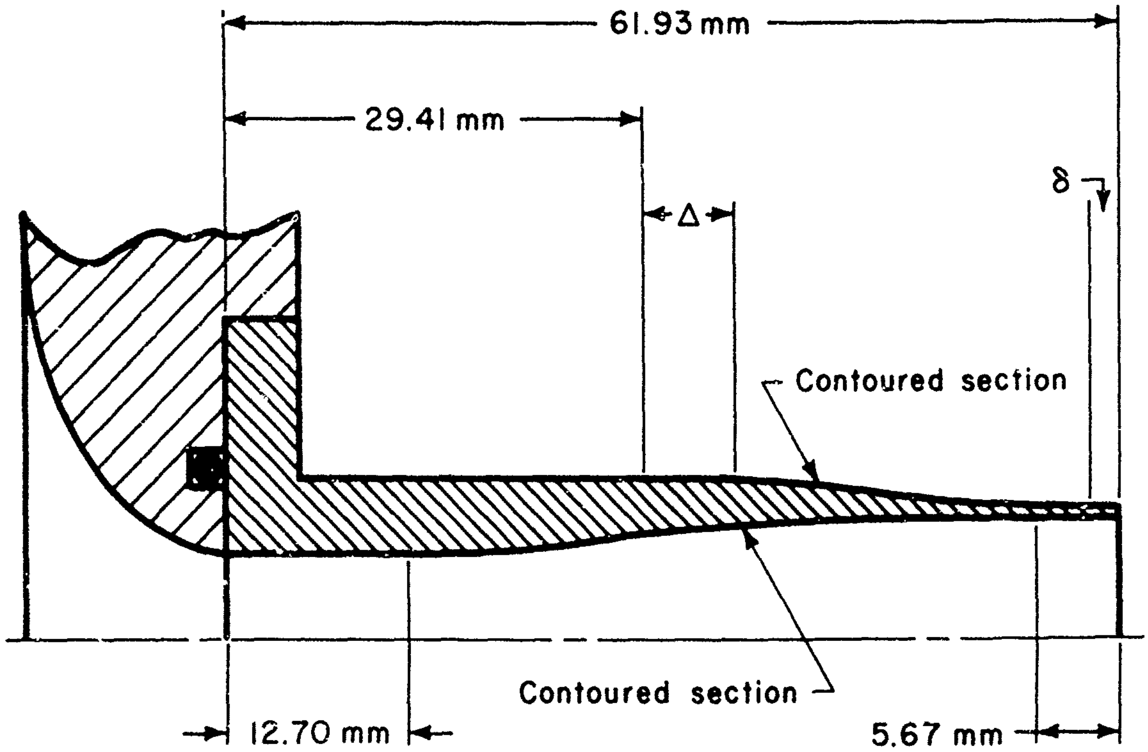


Figure 3.1-3 Enlargement of a Typical Continuous-Slope, Supersonic-Supersonic Nozzle



	Nozzle		
	M_{SI}	Δ (mm)	δ (mm)
1	1.50	6.35	2.14
2	1 75	0	0
3	2.00	6.35	2.18
4	2.50	2.11	0

Figure 3.1-4 Section View for the Continuous-Slope Nozzles with Specifications for the Nozzle Wall Profiles

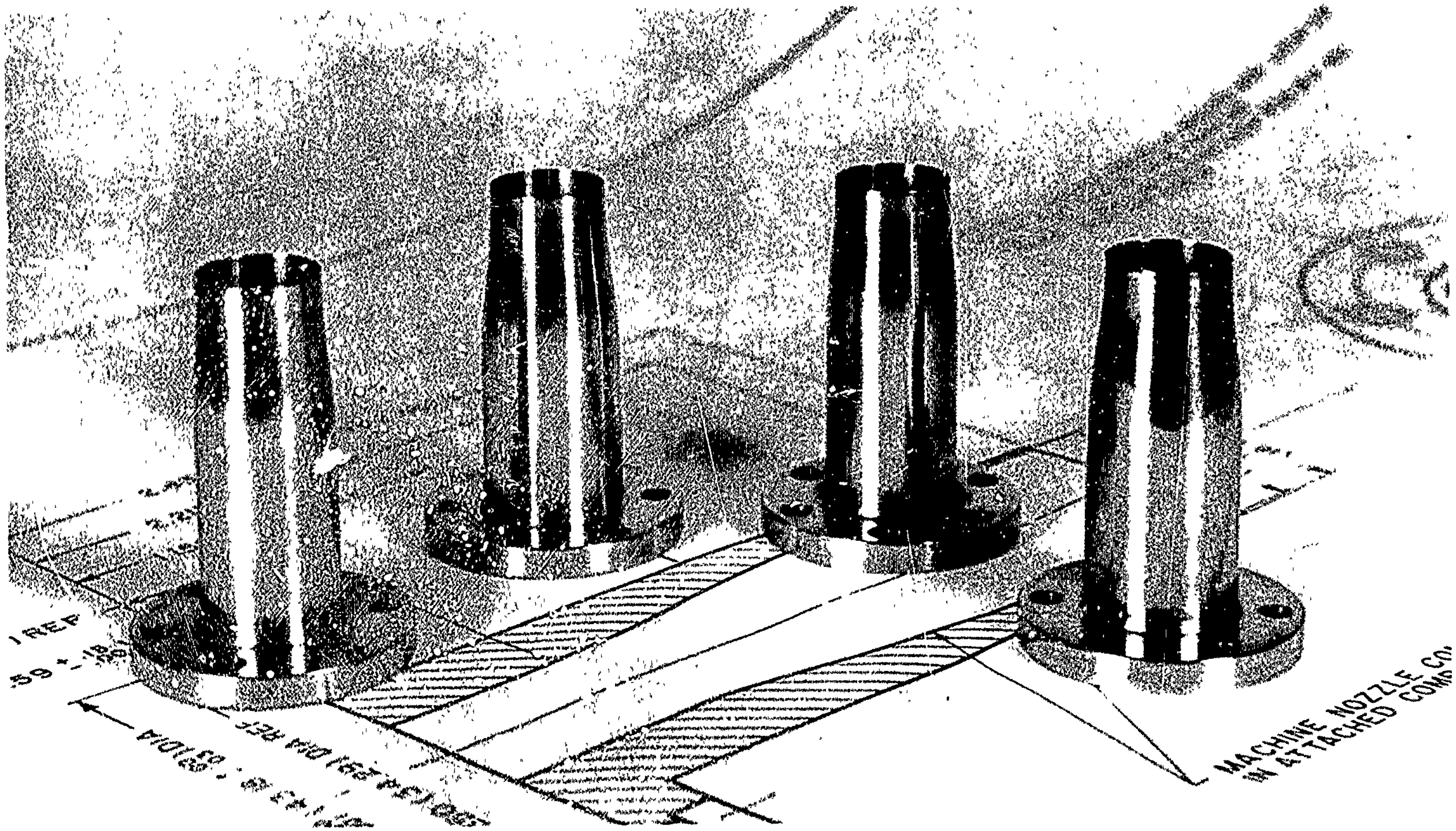
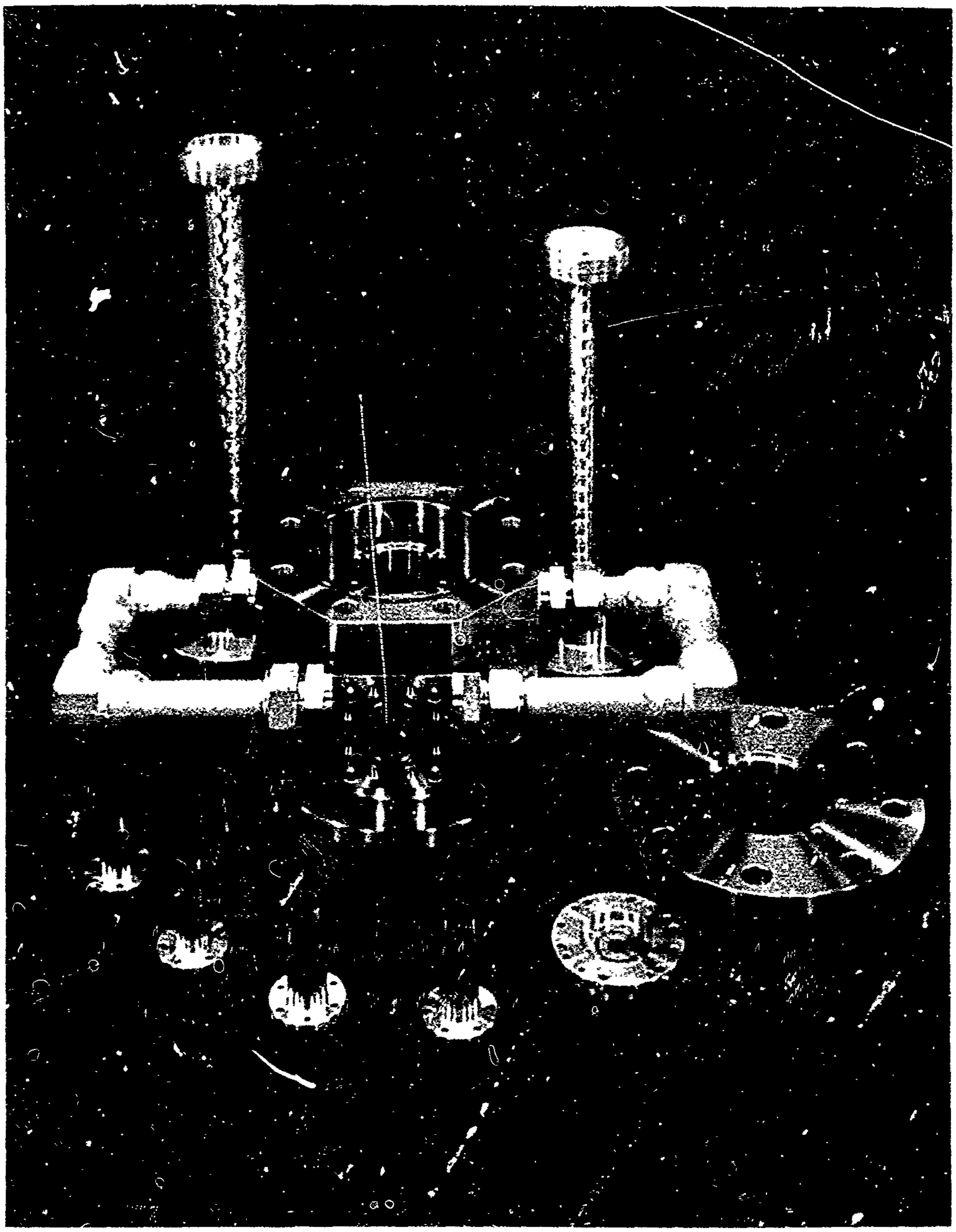
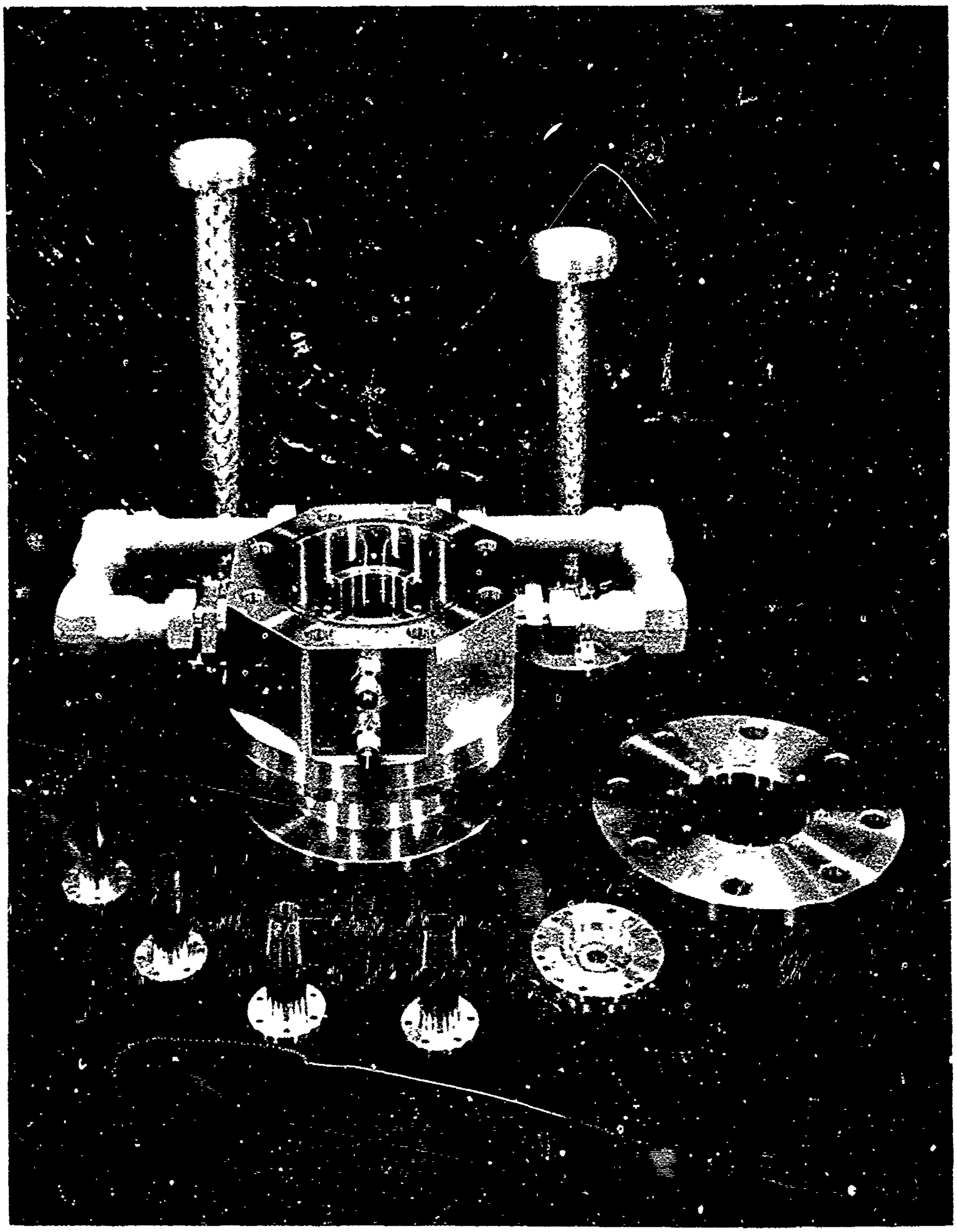


Figure 3.1-5 Photograph of the Continuous-Slope, Supersonic-Supersonic Nozzles



(a) Front View of the Secondary Stagnation Chamber

Figure 3.1-6 Photographs of the Ejector Model Components



(b) Rear View of the Secondary Stagnation Chamber

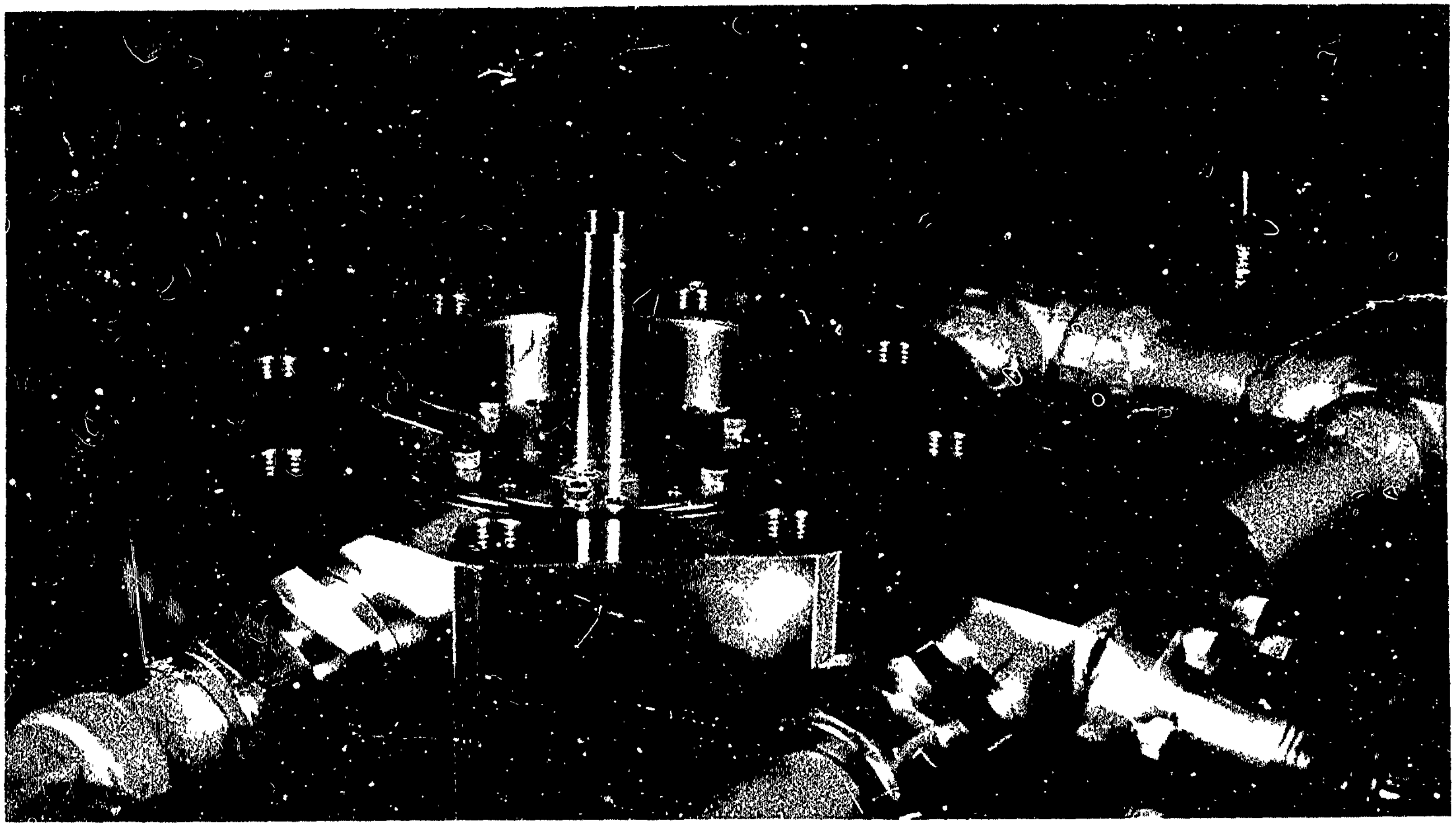


Figure 3.1-7 Partial Assembly of the Axisymmetric Ejector Model Showing the Position of the Supersonic-Supersonic Nozzle in the Secondary Stagnation Chamber

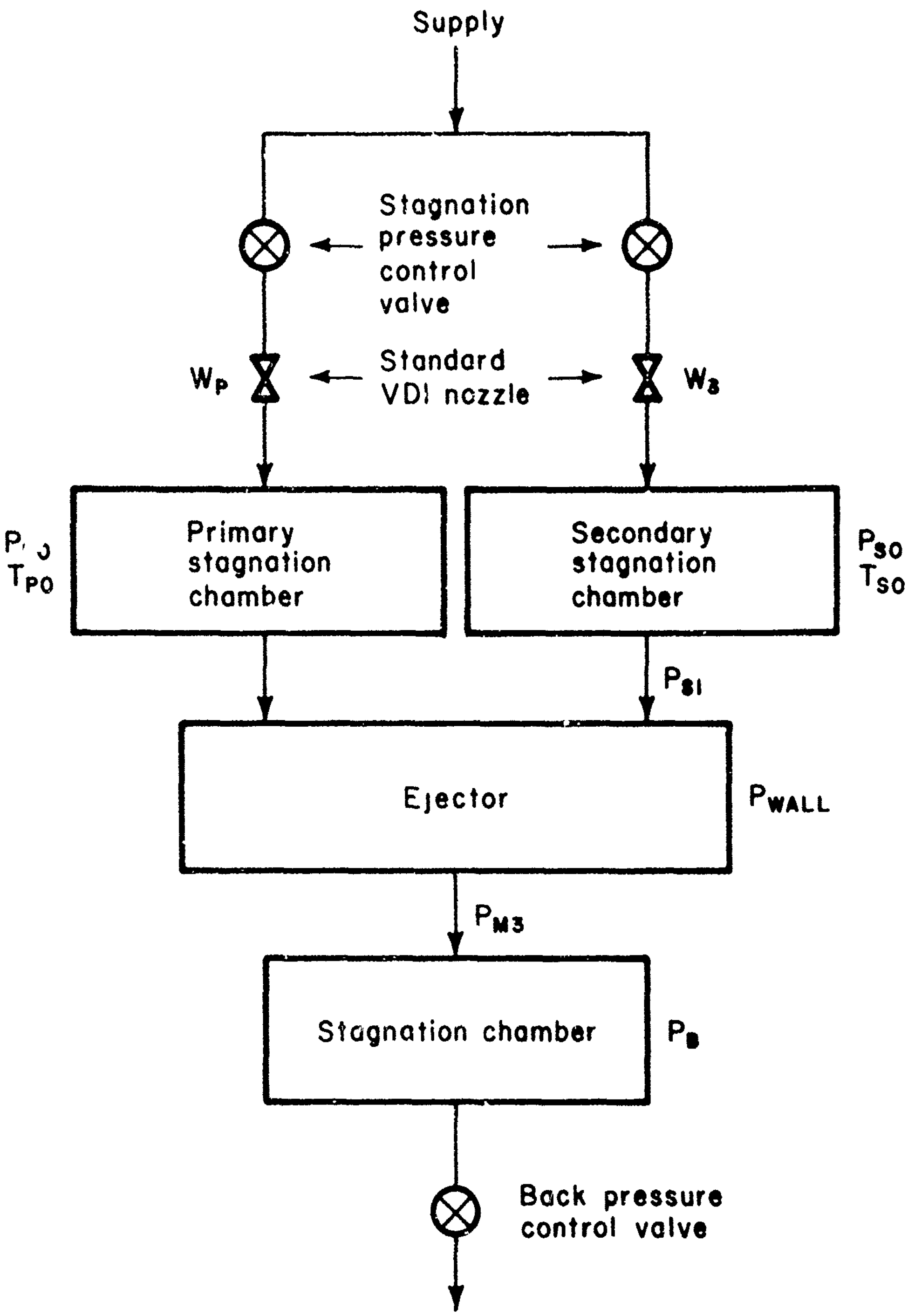


Figure 3.1-8 Ejector Experiment Flow Diagram

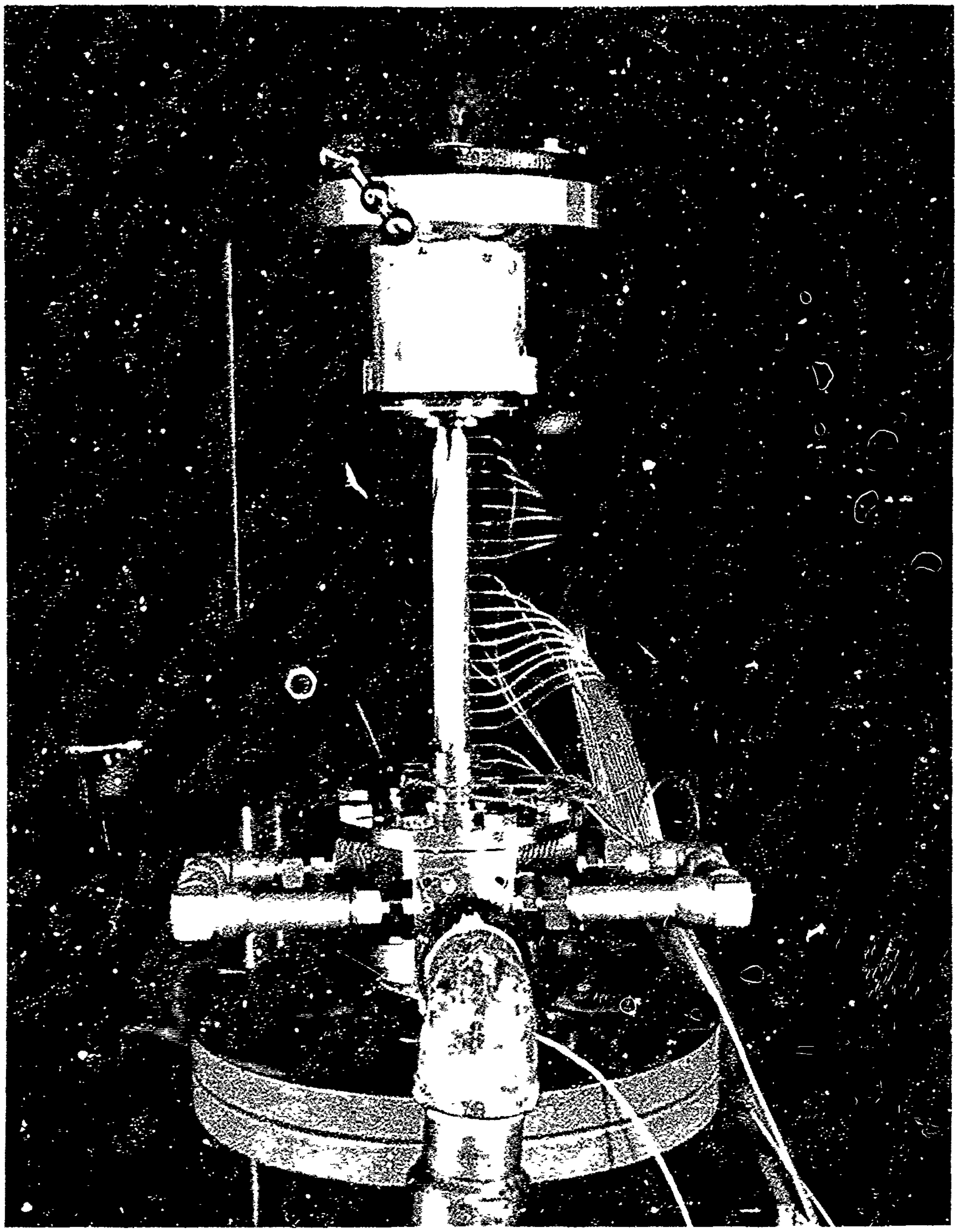


Figure 5.1-9 Photograph of the Ejector Model Installed on the Test Chamber with the Back Pressure Control Valve Located Downstream of the Mixing Tube

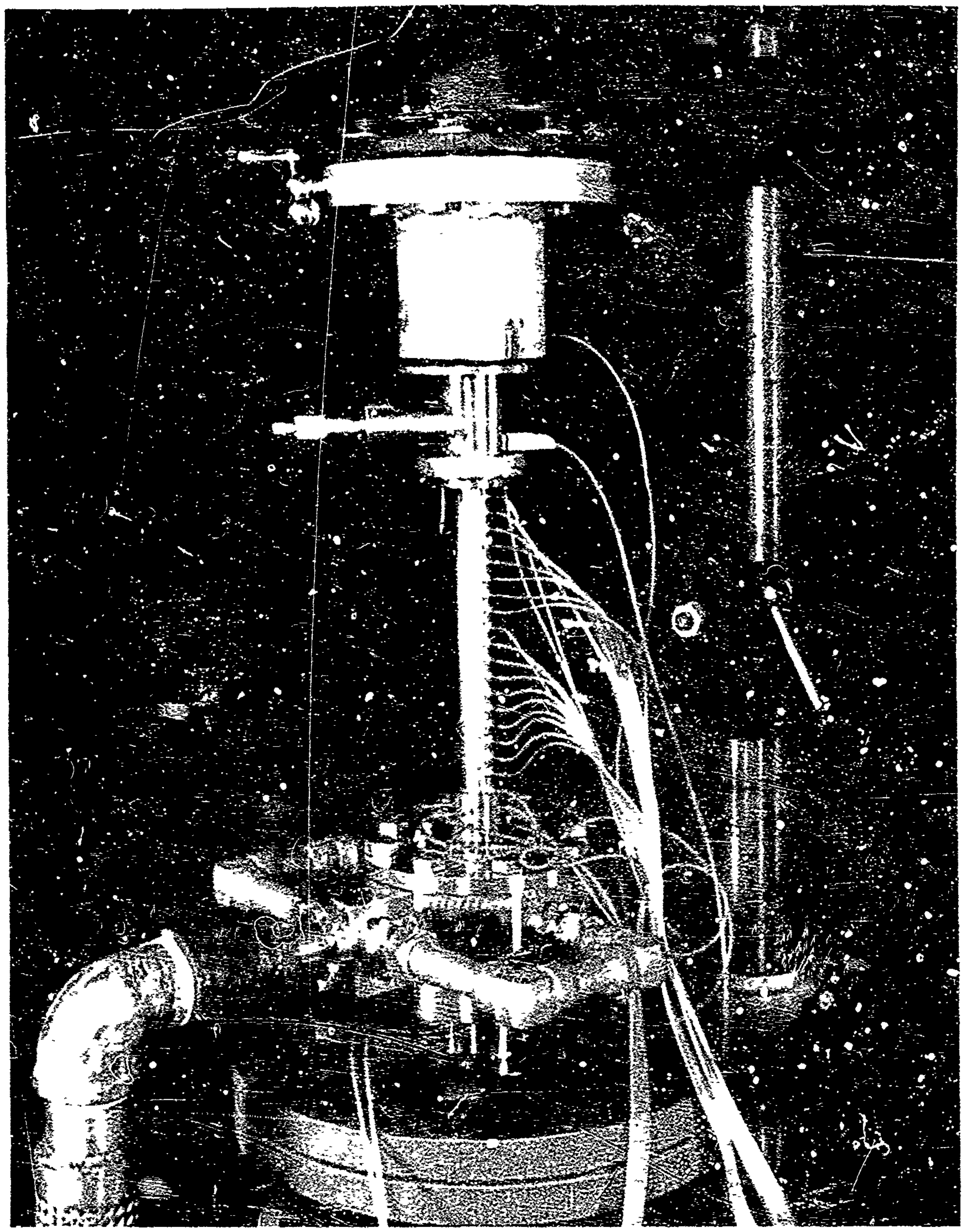


Figure 3.3.10 Photograph of the Ejector Model Installed on the Test Chamber with the Pitot Probe Located between the Mixing Tube and Back Pressure Control Valve

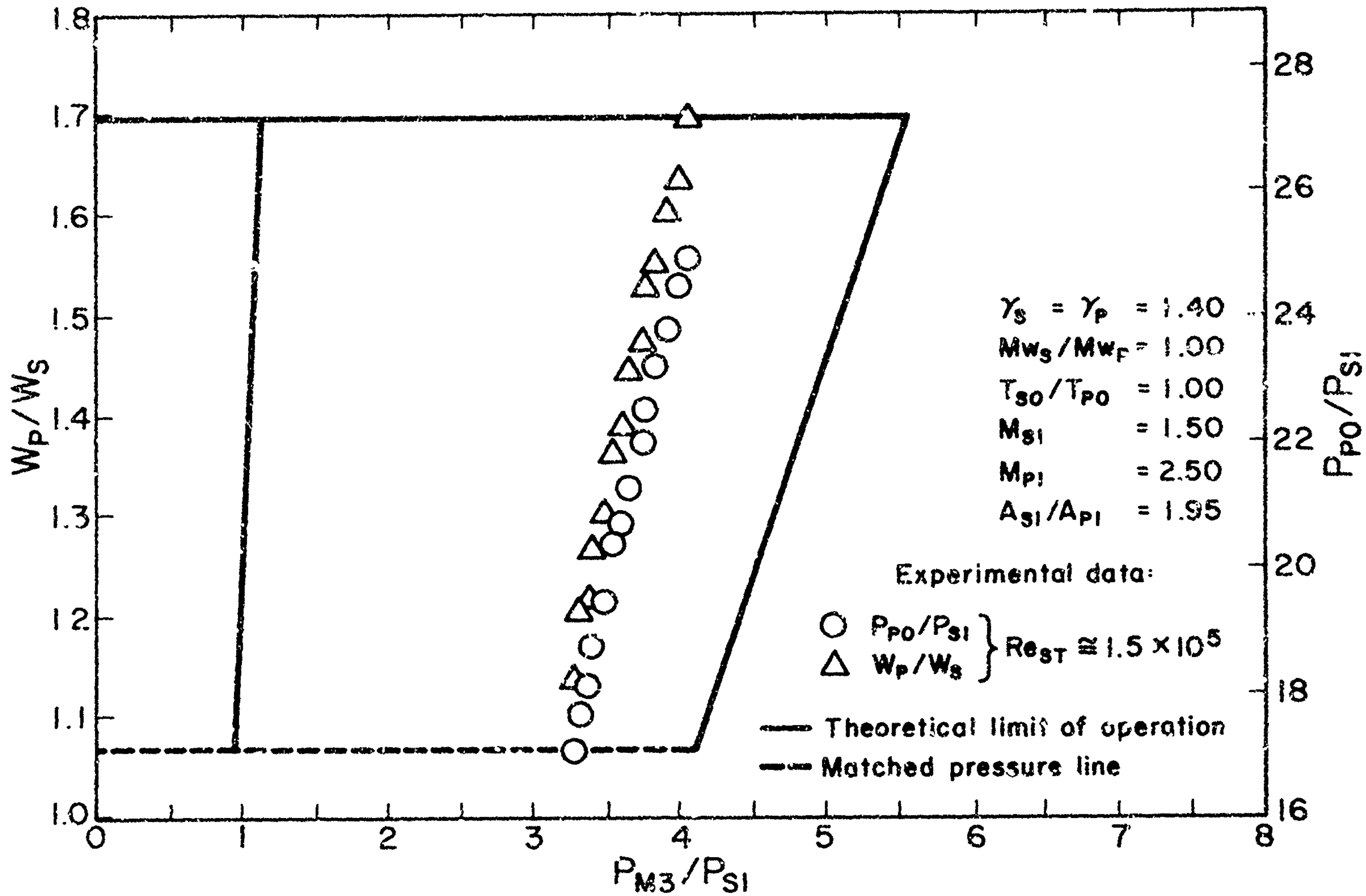


Figure 3.3-1 Maximum Compression Characteristics for the Constant-Area, Supersonic-Supersonic Ejector (M_{S1} = 1.50)

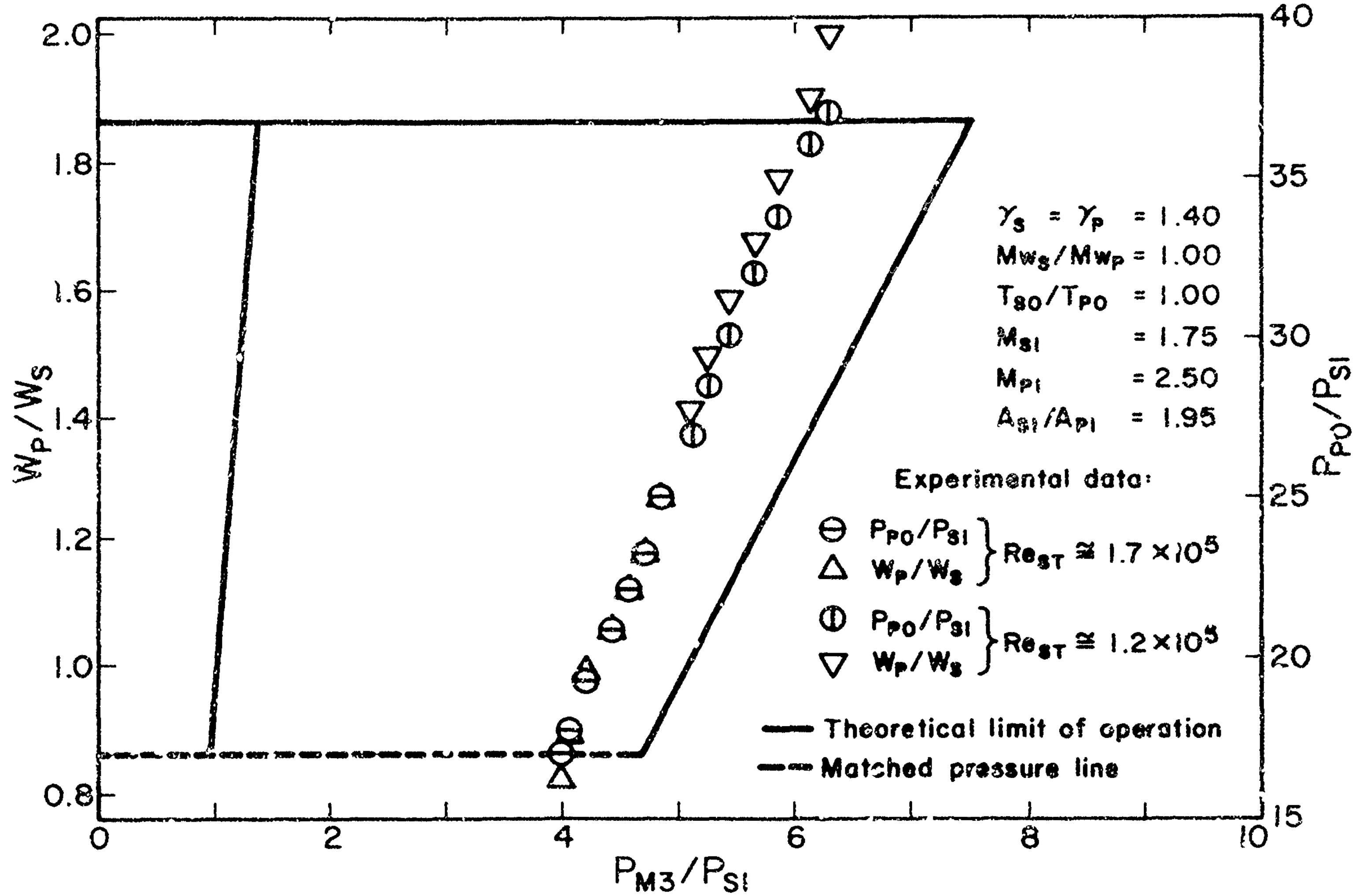


Figure 3.3-2 Maximum Compression Characteristics for the Constant-Area, Supersonic-Supersonic Ejector (M_{S1} = 1.75)

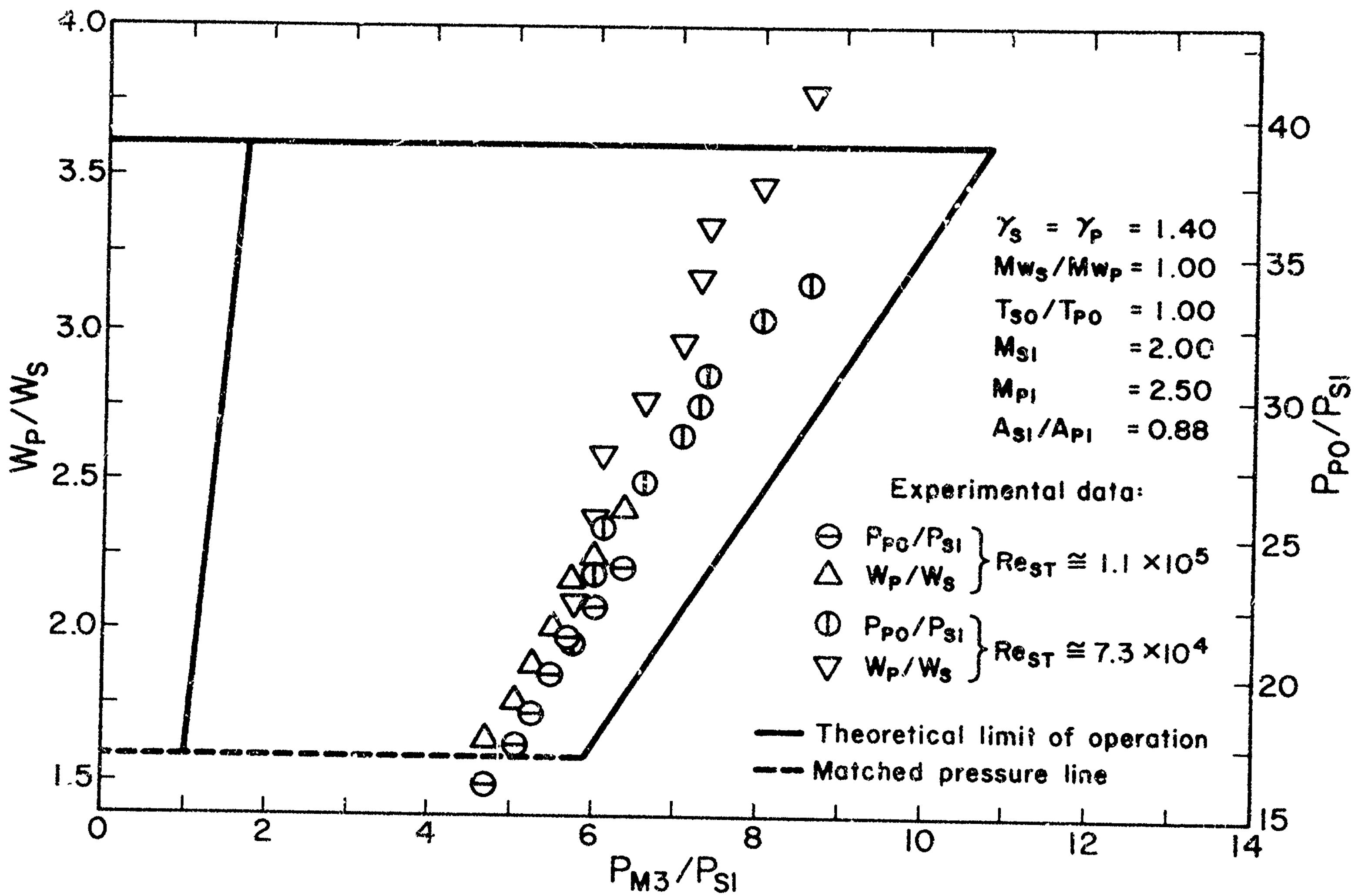


Figure 3.3-3 Maximum Compression Characteristics for the Constant-Area, Supersonic-Supersonic Ejector (M_{S1} = 2.00)

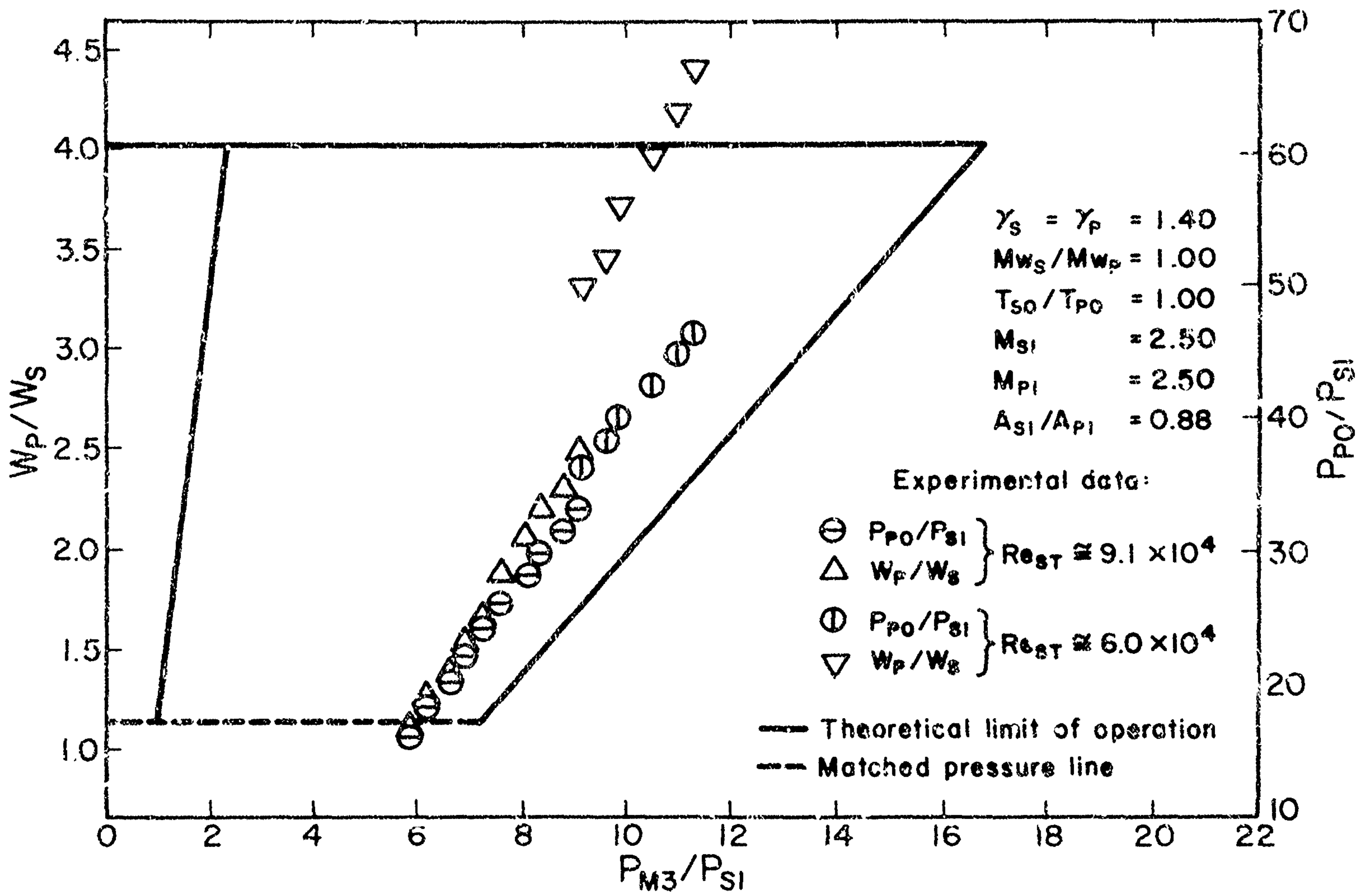


Figure 3.3-4 Maximum Compression Characteristics for the Constant-Area, Supersonic-Supersonic Ejector (M_{S1} = 2.50)

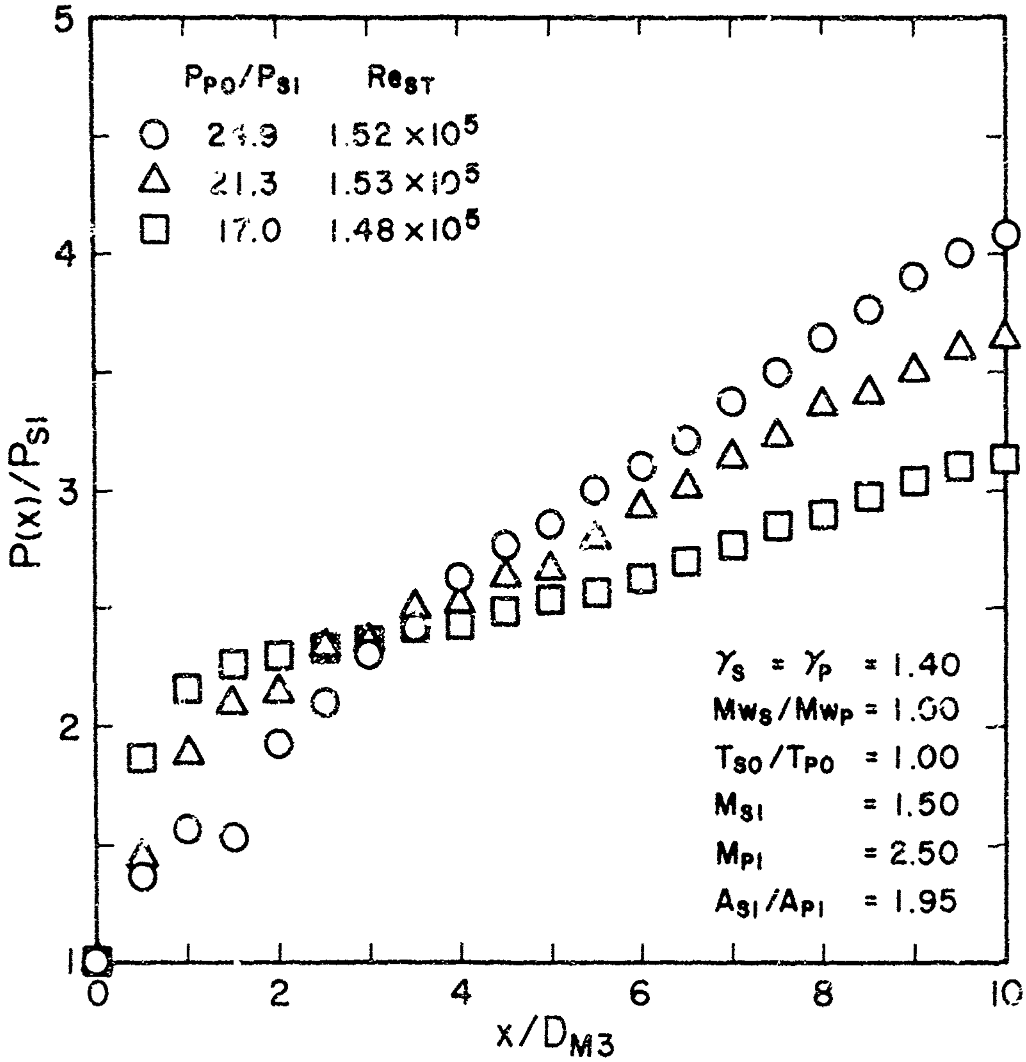


Figure 3.3-5 Wall Pressure Distributions for the Constant-Area, Supersonic-Supersonic Ejector at Maximum Compression Conditions (M_{S1} = 1.50)

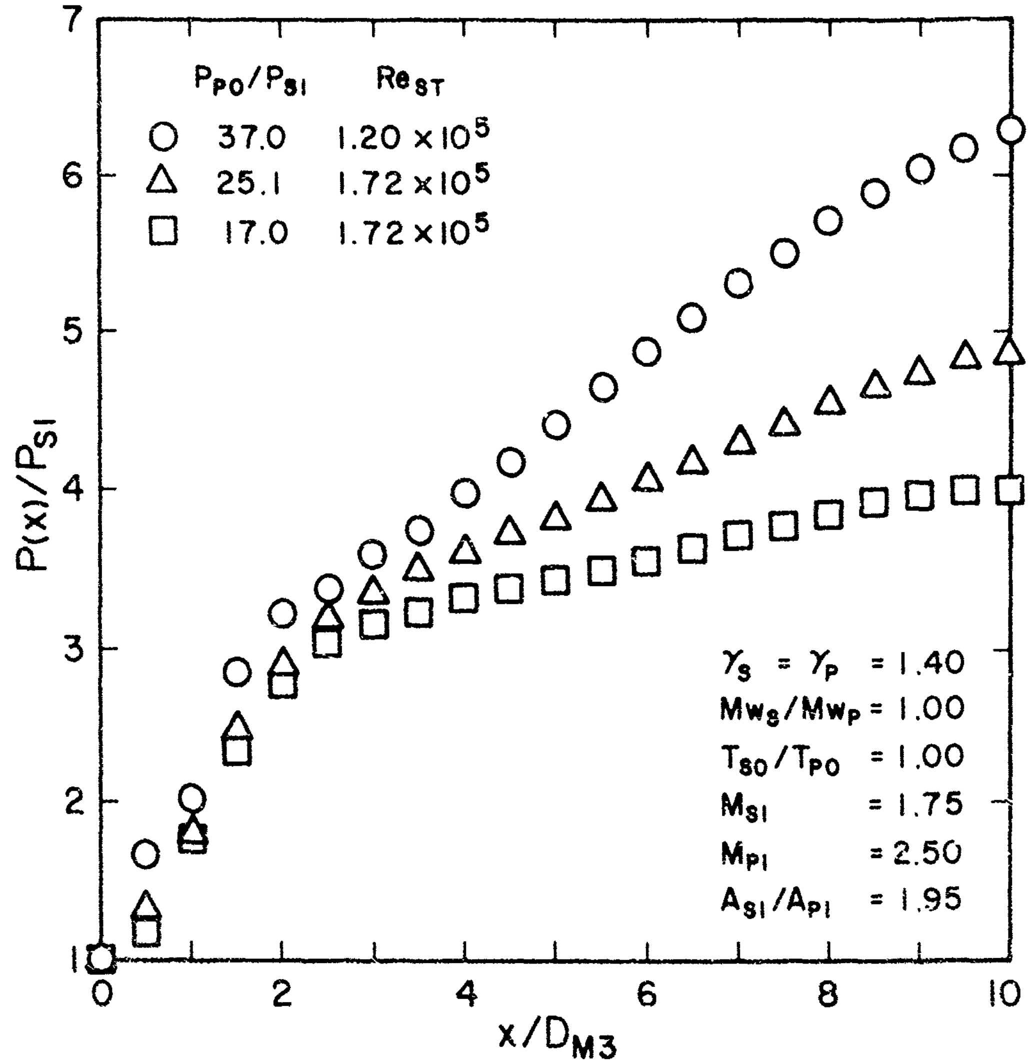


Figure 3.3-6 Wall Pressure Distributions for the Constant-Area, Supersonic-Supersonic Ejector as Maximum Compression Conditions (M_{S1} = 1.75)

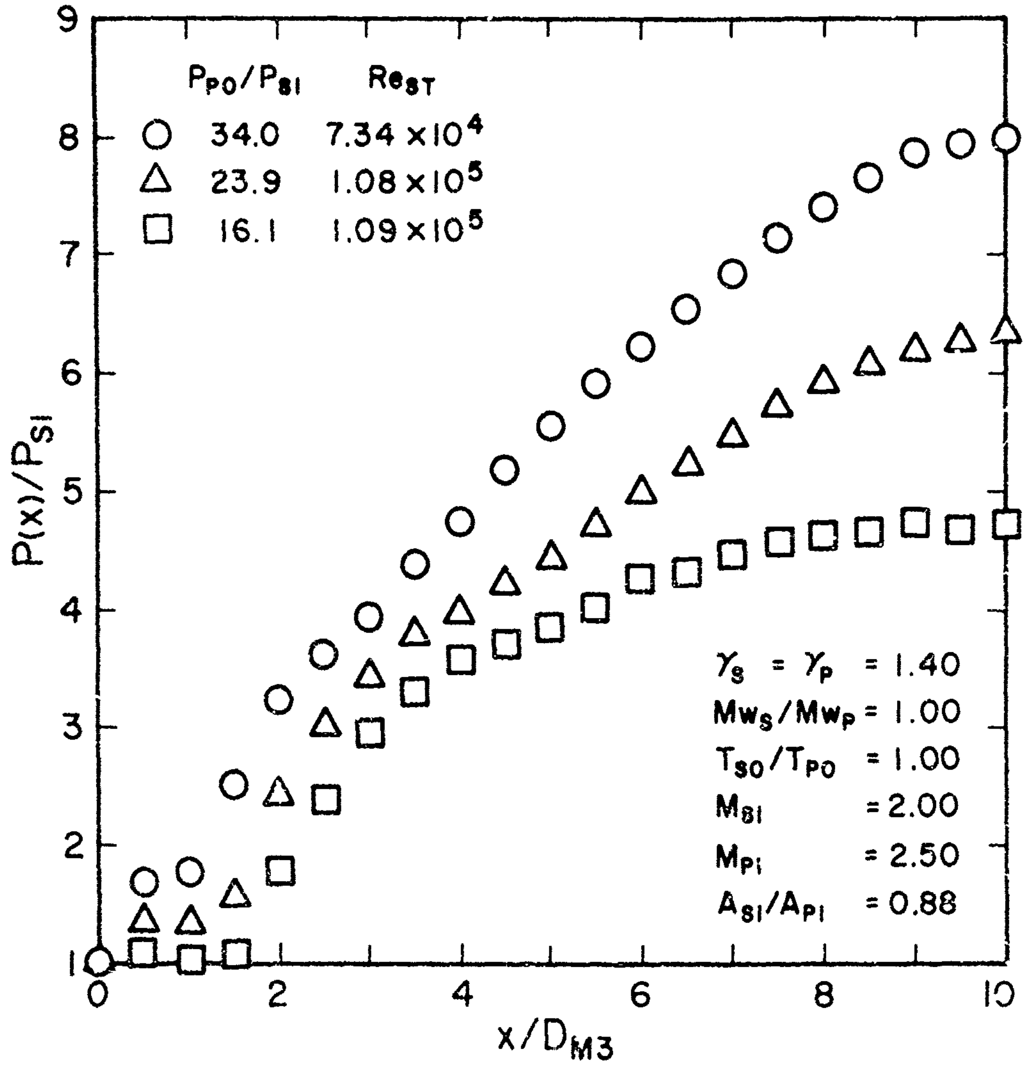


Figure 3.3-7 Wall Pressure Distributions for the Constant-Area, Supersonic-Supersonic Ejector at Maximum Compression Conditions (M_{S1} = 2.00)

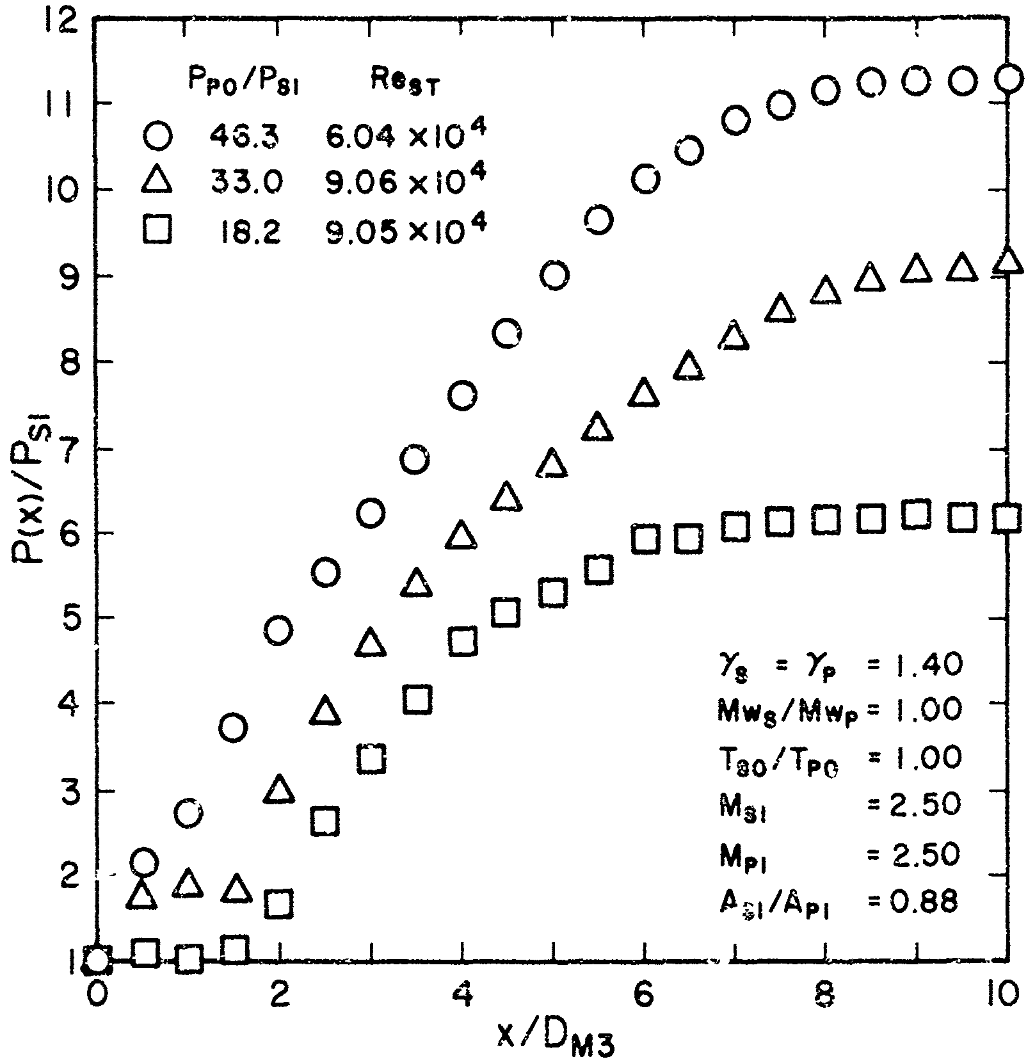


Figure 3.3-8 Wall Pressure Distributions for the Constant-Area, Supersonic-Supersonic Ejector at Maximum Compression Conditions (M_{S1} = 2.50)

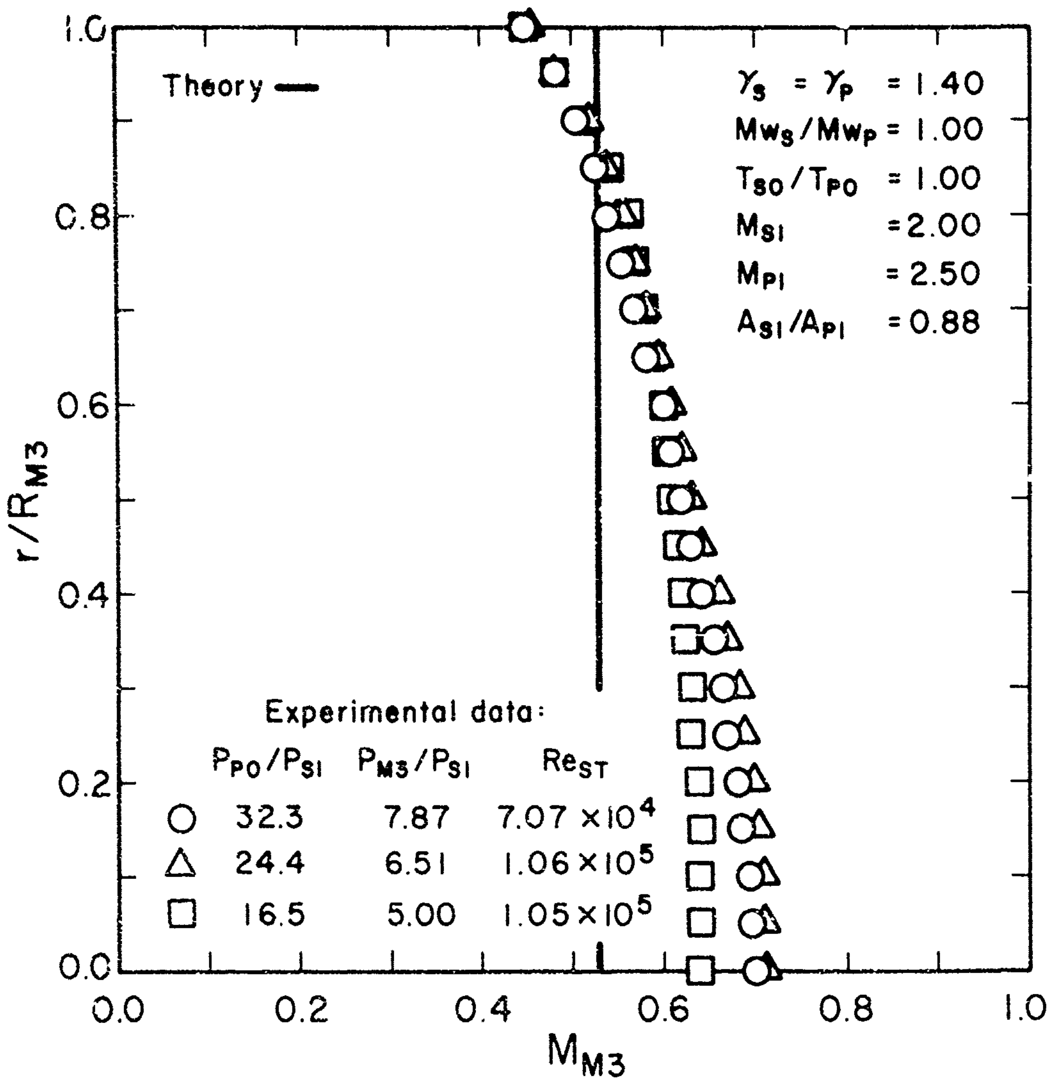
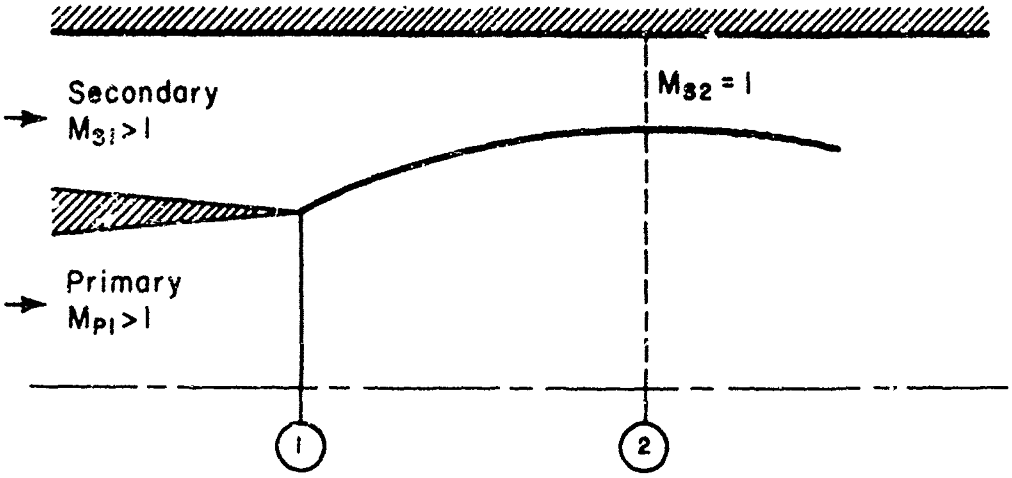
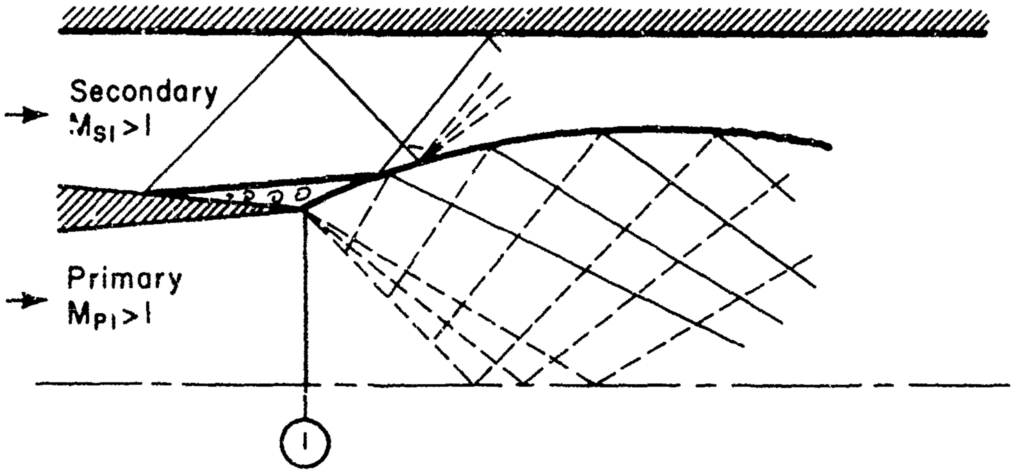


Figure 3.3-9 Exit Mach Number Distributions for the Constant-Area, Supersonic-Supersonic Ejector at Maximum Compression Conditions (M_{S1} = 2.00)



(a) Without Secondary Separation



(b) With Secondary Separation

Figure 3.3-10 Schematic of Secondary Flow Separation Induced by the Primary Flow

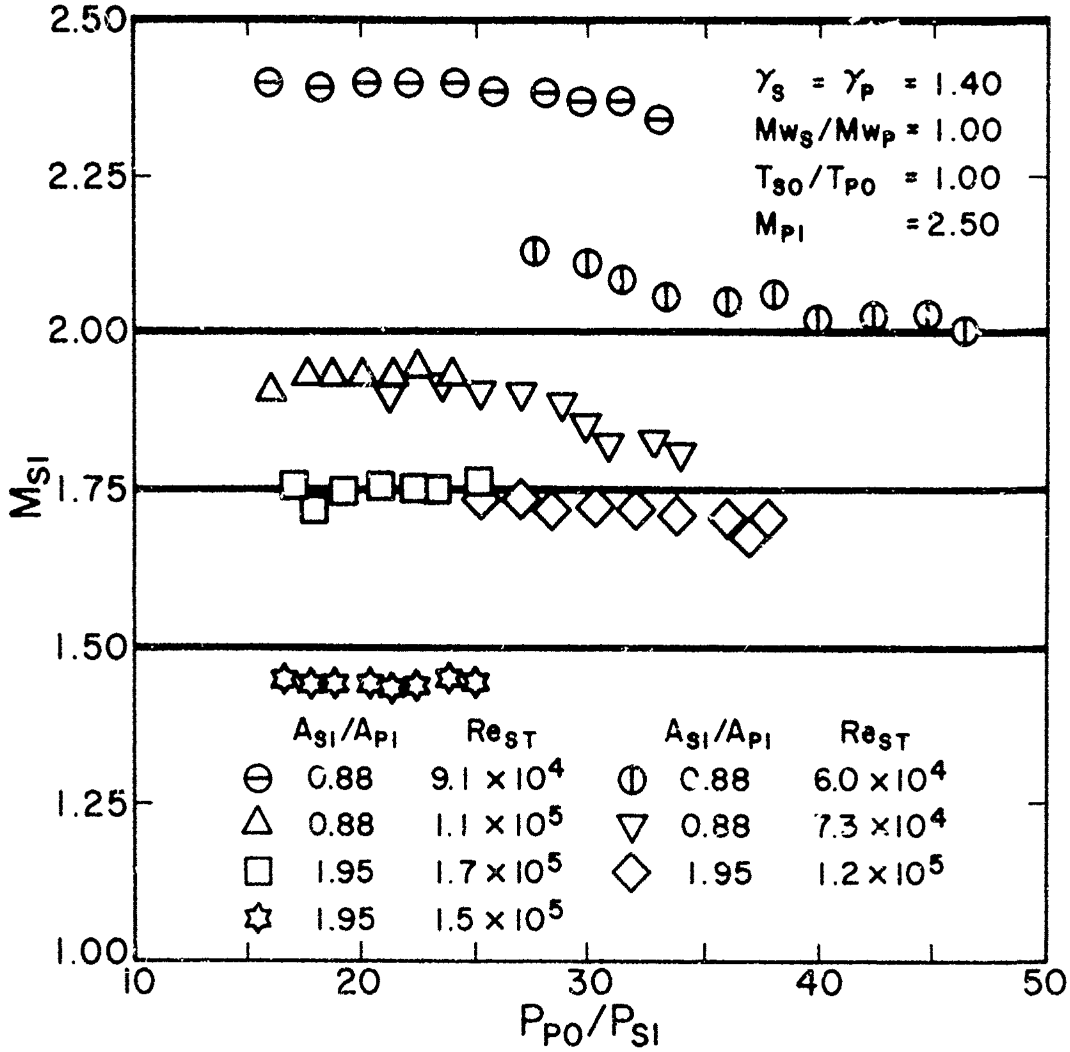


Figure 3.3-11 Variation in the Secondary Mach Number at the Mixing Tube Entrance with Primary Stagnation Pressure and Secondary Nozzle Reynolds Number

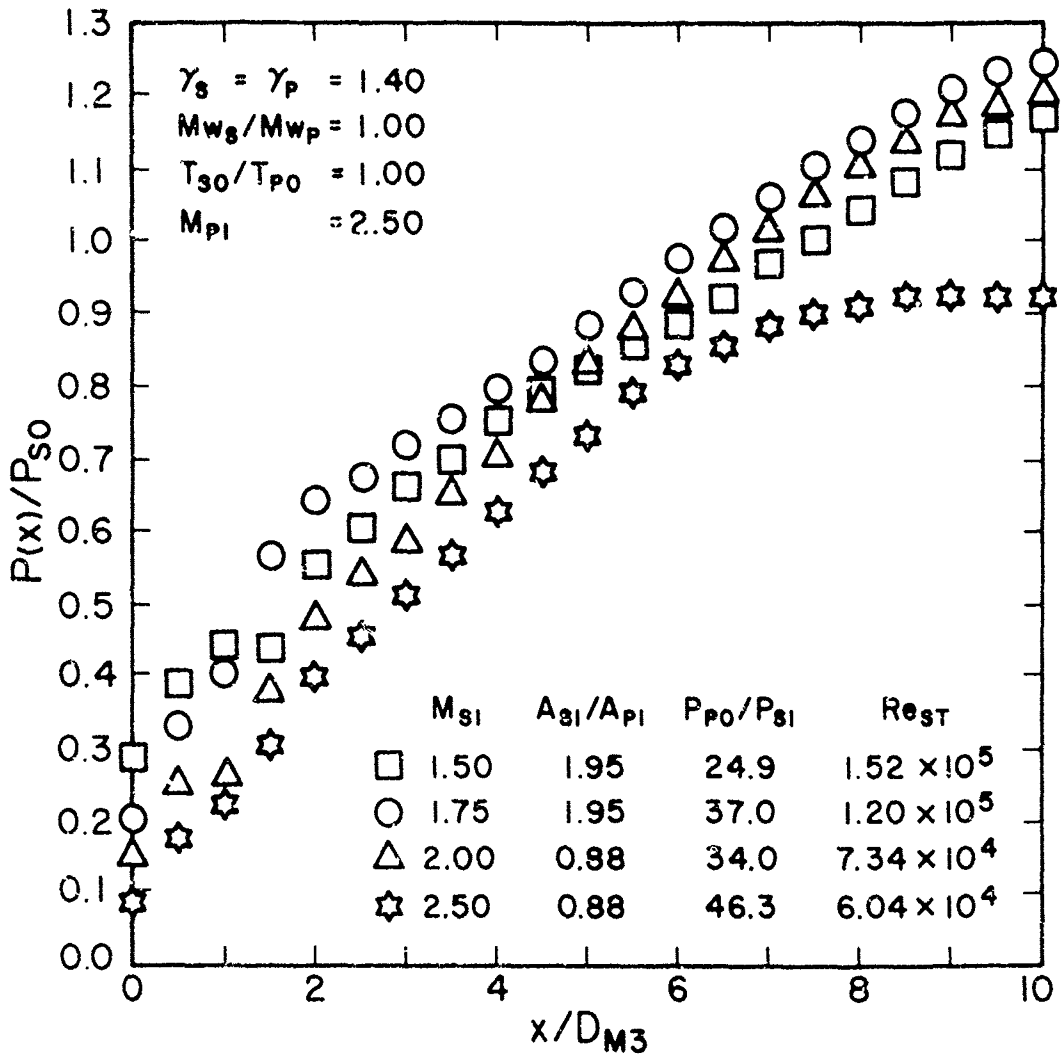


Figure 3.3-12 Wall Pressure Distributions for the Constant-Area, Supersonic-Supersonic Ejector Near the Upper Limit Point

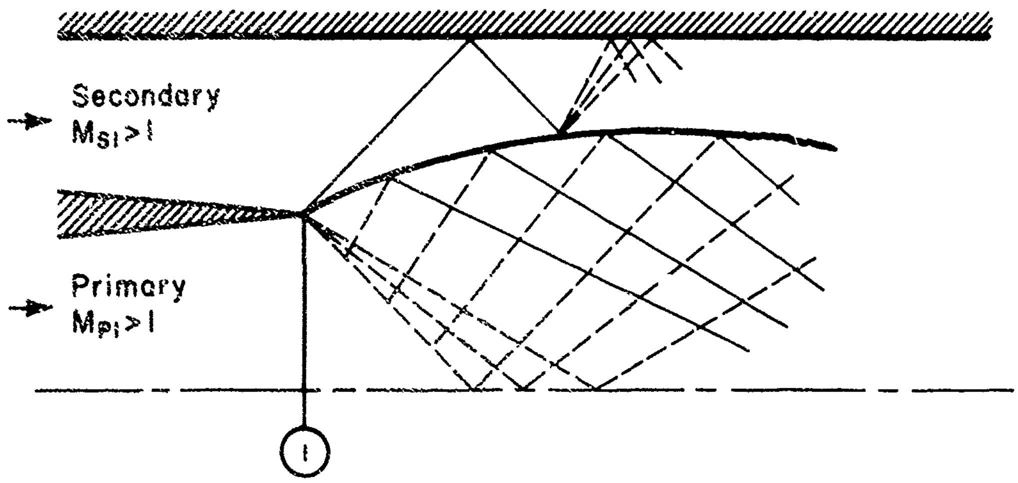


Figure 3.3-13 Schematic of a "Two Shock" Model for the Constant-Area, Supersonic-Supersonic Ejector

4.0 EJECTOR OPTIMIZATION AND COMPARISON OF THE CONSTANT-AREA, SUBSONIC-SUPERSONIC AND SUPERSONIC-SUPERSONIC EJECTORS

One purpose of this investigation was to compare the performance of the constant-area, supersonic-supersonic ejector with that of the constant-area, subsonic-supersonic ejector as applied to high-energy chemical laser systems. Because of the large number of parameters involved, it appears that the only fair comparison of the two ejectors must be based on optimum data for a supersonic-supersonic pumping system and a subsonic-supersonic pumping system. To this end, a method was developed for optimizing these two pumping systems within a given set of constraints. This method is based entirely on one-dimensional, compressible flow theory with a limited use of empirical data.

4.1 RELATIONSHIP OF THE CONSTANT-AREA SUBSONIC-SUPERSONIC EJECTOR TO THE CONSTANT-AREA SUPERSONIC-SUPERSONIC EJECTOR

The performance characteristics of the constant-area, subsonic-supersonic ejector and constant-area, supersonic-supersonic ejector are quite similar, the primary difference being the range of M_{S1}.

Given γ_S, γ_P, Mw_S/Mw_P, T_{S0}/T_{P0}, and A_{S1}/A_{P1}, the performance characteristics of the constant-area, subsonic-supersonic ejector, as shown schematically in Fig. 4.1-1, are described by a three-dimensional surface with axis M_{S1}, P_{S1}/P_{P0}, and P_{M3}/P_{P0}. Since the secondary entrance forms a converging nozzle, M_{S1} may take on any value in the range 0 to 1. For $P_{P1} > P_{S1}$, the primary stream expands inside the mixing tube and the secondary stream is reaccelerated to, at most, sonic conditions. Should the secondary stream be thus choked, the ejector operation becomes independent of P_{M3}/P_{P0} as indicated by two faces of the characteristic

surface which lie parallel to the P_{M3}/P_{P0} axis. The curve marking the transition from the P_{M3}/P_{P0} independent to dependent regimes is known as the "break-off" curve and is considered to represent the optimum conditions for ejector operation.†

Given γ_S, γ_P, Mw_S/Mw_P, T_{S0}/T_{P0}, and A_{S1}/A_{P1}, the performance characteristics of the constant-area, supersonic-supersonic ejector, as shown schematically in Fig. 4.1-2, are also described by a three-dimensional surface with axis M_{S1}, P_{S1}/P_{P0}, and P_{M3}/P_{P0}; however, the ejector operation is restricted to only a portion of the surface. So long as the entering secondary stream remains supersonic, as assumed in Section 2.0, M_{S1} will be at the supersonic design value as produced by the generating device, e.g. a laser cavity, and the ejector is confined to the plane of supersonic-supersonic operation. If P_{M3}/P_{P0} is increased beyond the limit of maximum P_{M3}/P_{P0} for supersonic-supersonic operation, then a normal shock wave will pass into the secondary entrance and M_{S1} must undergo a step change to the normal shock value as indicated in Fig. 4.2-2(a). If, alternately, P_{S1}/P_{P0} is decreased beyond the upper limit line for supersonic-supersonic operation, then the secondary stream is recompressed in the mixing tube to an area less than A* for the supersonic design value of M_{S1}, and M_{S1} must drop to the subsonic design value of the generating device. However, if P_{S1}/P_{P0} is now increased, the entering secondary flow will again go supersonic, similar to a second-throat, supersonic diffuser, with M_{S1} first increasing to the normal shock value before a step change to the supersonic design value.

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†See references [1,8,10,11] for a complete description of constant-area, subsonic-supersonic ejector operation.

The similarity in performance characteristics of the constant-area, subsonic-supersonic ejector and constant-area, supersonic-supersonic ejector becomes even more apparent as the supersonic design value of M_{S1} in Fig. 4.1-2(a) approaches 1 since the normal shock value also approaches 1 and, in the limit, Fig. 4.1-2(a) becomes identical to Fig. 4.1-1(a).

4.2 OPTIMIZATION OF THE CONSTANT-AREA, SUBSONIC-SUPERSONIC AND SUPERSONIC-SUPERSONIC EJECTORS

Referring to the high-energy, chemical laser system schematic of Fig. 4.2-1, the laser cavity, stations 1 to 2, has no influence on the pumping system other than establishing the flow conditions at point 2. Hence, the laser cavity can be replaced by a supersonic wind tunnel or any other device producing a uniform, supersonic stream. A one-dimensional analysis for laser cavity flows with heat addition is available [1] and was included in a computerized version of the optimization procedure.

The constant-area, normal shock diffuser, stations 2 to 3 of Fig. 4.2-1, diffuses the entering supersonic stream to its normal shock value. The static pressure ratio across the duct is expressed by

$$P_3/P_2 = R_{NSD}\, f(\gamma_S , M_2)$$

where R_{NSD} is an empirical normal shock coefficient and $f(\gamma_S , M_2)$ is the usual normal shock static pressure ratio function. Values of R_{NSD} in the range $0.75 \leq R_{NSD} \leq 1.25$ are commonly used for parametric studies [1].

The static pressure rise across the subsonic diffuser, stations 3 to 4 of Fig. 4.2-1, is given by

$$(P_4 - P_3)_{ACTUAL} = \eta(P_4 - P_3)_{IDEAL}$$

where η is an empirical diffuser efficiency and $(P_4 - P_3)_{IDEAL}$ is a function of γ_S, M_3, and A_4/A_3. As a simplification, η was taken from a curve fit of experimental data given in [17,18] for 15° conical, subsonic diffusers with

$$\eta = 1.048992 - 0.027229\ (A_4/A_3) - 0.024461\ (A_4/A_3)^2 + 0.002685\ (A_4/A_3)^3 \ ,$$

$$1.0 \leq A_4/A_3 \leq 5.2 \ .$$

This empirical relation was also applied to the subsonic diffuser at stations 7 to 8.

Although stagnation pressure losses are encountered in sudden enlargements, these losses were ignored in the subsonic-supersonic pumping system of Fig. 4.2-1.

Finally, the one-dimensional analysis for the constant-area, supersonic-supersonic ejector of Fig. 4.2-1 was taken from Section 2.0, and the corresponding analysis for the constant-area, subsonic-supersonic ejector was taken from Addy and Mikkelsen [1].

Then given γ_S, M_2, R_{NSD}, A_4/A_3, γ_P, Mw_P/Mw_S, T_{60}/T_{50}, A_8/A_7, P_{60}/P_2, and P_8/P_2 for the subsonic-supersonic pumping system, or γ_S, M_2, γ_P, Mw_P/Mw_S, T_{60}/T_{20}, A_8/A_7, P_{60}/P_2, and P_8/P_2 for the supersonic-supersonic pumping system, the optimum is considered to be that ejector, as specified by M_6 and A_7/A_6 which requires the minimum W_P/W_S; or, alternately, the minimum P_{60}/P_2 when W_P/W_S is specified. In general, γ_S, M_2, γ_P, Mw_P/Mw_S, and T_{60}/T_{50} (or T_{60}/T_{20}) are known and P_8/P_2 and P_{60}/P_2 (or W_P/W_S) are the constraints of primary interest.

Now consider the simplified supersonic-supersonic pumping system of Fig. 4.2-1 with $A_8/A_7 = 1$, i.e. with no subsonic diffuser and γ_S, γ_P,

Mw_p/Mw_s, T_{60}/T_{20}, and M_2 as known constants. Then given M_6 and A_2/A_6, upper limit point values of P_7/P_2, P_{60}/P_2, and W_p/W_s are obtained from the one-dimensional theory of Section 2.0. Figure 4.2-2 is a plot of M_6 vs. P_7/P_2 at the upper limit point over a range of A_2/A_6 for this system. If the compression ratio P_7/P_2 is chosen to be, say, 20, then all possible combinations of M_6 and A_2/A_6 satisfying this constraint are determined by the verticle dashed line.

Figure 4.2-3 is a cross plot of P_{60}/P_2 and W_p/W_s vs. A_2/A_6 for the combinations of M_6 and A_2/A_6 of Fig. 4.2-2 satisfying the constraint on P_7/P_2. From this graph it is apparent that P_{60}/P_2 varies inversely with W_p/W_s and that if an upper limit is established for P_{60}/P_2, say, at 1000, then the minimum value of W_p/W_s, in this case $W_p/W_s = 3.2$, will occur at that upper limit. The optimum ejector is, therefore, fully determined since $A_2/A_6 = 4.4$ for $P_{60}/P_2 = 1000$ and $M_6 = 4.4$ from Fig. 4.2-2. If, for example, an upper limit of 6 is set for W_p/W_s, then the minimum value of P_{60}/P_2, in this example $P_{60}/P_2 = 217$, will occur at $A_2/A_6 = 1$, corresponding to the upper limit value of W_p/W_s in Fig. 4.2-3 and $M_6 = 3.7$ from Fig. 4.2-2.

This procedure for optimizing the supersonic-supersonic pumping system of Fig. 4.2-1 is not significantly altered by the addition of a subsonic diffuser at stations 7 to 8. Figures 4.2-2 and 4.2-3 are still sufficient; however, the overall compression ratio P_8/P_2 is substituted for P_7/P_2.

The optimization procedure for the subsonic-supersonic pumping system of Fig. 4.2-1 is nearly identical to the procedure outlined above for the supersonic-supersonic pumping system, with Figs. 4.2-4 and 4.2-5

corresponding to Figs. 4.2-2 and 4.2-3, respectively; however, one additional variable is involved since M_5 may take on any value in the range $0 \leq M_5 \leq 1$. The result is that Figs. 4.2-4 and 4.2-5 must be reproduced for all values of M_5 which give solutions satisfying the constraints on P_7/P_2 and P_{60}/P_2 (or alternately W_p/W_s). Once this is accomplished, the minimum values of W_p/W_s (or alternately P_{60}/P_2) can be cross plotted vs. M_5 to find the absolute minimum as shown in Figs. 4.2-6 and 4.2-7. This process completes the ejector specification since, for example, W_p/W_s and M_5 from Fig. 4.2-6 determine A_5/A_6 from Fig. 4.2-5, which in turn specifies M_6 from Fig. 4.2-4.

As an example of the optimization procedure for a subsonic-supersonic pumping system of Fig. 4.2-1 with R_{NSD}, A_4/A_3 and A_8/A_7 equal to 1, let $M_5 = 0.9$ as in Figs. 4.2-4 and 4.2-5 with constraints of $P_7/P_2 = 20$ and $P_{60}/P_2 = 1000$. Since P_{60}/P_2 varies inversely with W_p/W_s in Fig. 4.2-5, the minimum value of W_p/W_s is 2.8 at $A_5/A_6 = 3.8$ and $M_6 = 4.5$ from Fig. 4.2-4. Repeating this process for all suitable values of M_5 and plotting the results, shown in Fig. 4.2-6, it can be seen that the absolute minimum value of W_p/W_s occurs at $M_5 = 0.9$ and the optimization is complete.

If in the preceding example an upper limit of $W_p/W_s = 6$ was selected rather than the constraint on P_{60}/P_2, then for $M_5 = 0.9$, the minimum value of P_{60}/P_2 would be 105 at $A_5/A_6 = 0.8$ from Fig. 4.2-5 and $M_6 = 2.8$ from Fig. 4.2-4. Now repeating this process for all values of M_5 yielding solutions which satisfy the system constraints and plotting the results shown in Fig. 4.2-7, it can be seen that the absolute minimum value of

P_{60}/P_2 occurs at $M_5 = 0.7$, rather than at $M_5 = 0.9$, and that the solution at $M_5 = 0.9$ is merely one step in the optimization process.

While this graphical method of ejector optimization is necessarily quite tedious, the entire process is readily adaptable to standard computer programing procedures. Some care, however, must be taken in the selection of M_5, A_5/A_6, and M_6 (or A_2/A_6 and M_6) since only certain combinations will yield solutions satisfying any one system constraint.

4.3 COMPARISON OF OPTIMUM CONSTANT-AREA, SUBSONIC-SUPERSONIC AND SUPERSONIC-SUPERSONIC EJECTOR DATA

Three sets of optimum data, as listed in Tables 4.3-1, 4.3-2, and 4.3-3, were calculated by the procedure of Section 4.2 for comparison of a supersonic-supersonic pumping system with a subsonic-supersonic pumping system as shown in Fig. 4.2-1. The first two cases represent typical high-energy, chemical laser system data while the third case demonstrates a supersonic wind tunnel application. In each case, the appropriate variable, either W_p/W_s or P_{60}/P_2, was minimized for the supersonic-supersonic pumping system and for the subsonic-supersonic pumping system with $R_{NSD} = 1.0$, 0.85, and 0.75. The exit-to-entrance area ratio for all the subsonic diffusers was arbitrarily set at 2.0. The optimum ejector for each case is specified by M_6 and A_7/A_6. The area ratio A_8/A_2 was also tabulated as an indication of the overall size of the pumping systems.

In selecting data for the hypothetical, supersonic wind tunnel configuration of Table 4.3-3, it was assumed that the secondary, or test section, nozzle and the ejector primary nozzle would both be supplied from a common source at the same stagnation pressure, in this case

790.8 kPa, and that the ejector system would pump to atmospheric conditions. This assumption precludes a minimization of P_{60}/P_2 since the compression ratio P_8/P_2 would be unknown.

The optimization method of Section 4.2 used only theoretical, supersonic-supersonic ejector data computed at upper limit point conditions. In defense of this procedure, Cases No. 1 and 2 were also calculated for a supersonic-supersonic pumping system at matched pressure conditions. A matched pressure calculation was unrealistic for the supersonic wind tunnel, Case No. 3, since this condition would only be satisfied if the secondary, or test section, nozzle and primary ejector nozzle (operating at equal stagnation pressures) had identical design Mach numbers.

Examination of the optimum data for Cases No. 1, 2, and 3 leads to several important conclusions:

1. For a fixed value of P_{60}/P_2, the minimum value of W_P/W_S for the supersonic-supersonic pumping system lies between the minimum value of W_P/W_S for the subsonic-supersonic pumping systems with R_{NSD} = 1.0 and 0.85. Since a value of $R_{NSD} \leq 0.85$ is most realistic, it appears that the supersonic-supersonic pumping system gives the best performance.

For a fixed value of W_P/W_S, the minimum value of P_{60}/P_2 for the supersonic-supersonic pumping system is equal to or greater than the minimum value of P_{60}/P_2 for the subsonic-supersonic pumping system with $R_{NSD} = 0.75$ indicating that the performance of the subsonic-supersonic pumping system is superior.

Clearly, the only conclusion to be drawn from this limited data is that the selection of one pumping system over the other on the bases of

mass flow ratio and primary stagnation pressure depends entirely on the system constraints and that no broad statement can be made as to one pumping system performing better than the other.

2. Upper limit point conditions are preferred over matched pressure conditions in the optimization of supersonic-supersonic pumping systems since the resultant system requires much lower values of W_P/W_S and P_{60}/P_2. The same conclusion, though not proven, should apply to all values of P_6/P_2 between the matched pressure and upper limit points since P_7/P_2 varies linearly with W_P/W_S and P_{60}/P_2 (see Section 2.0).

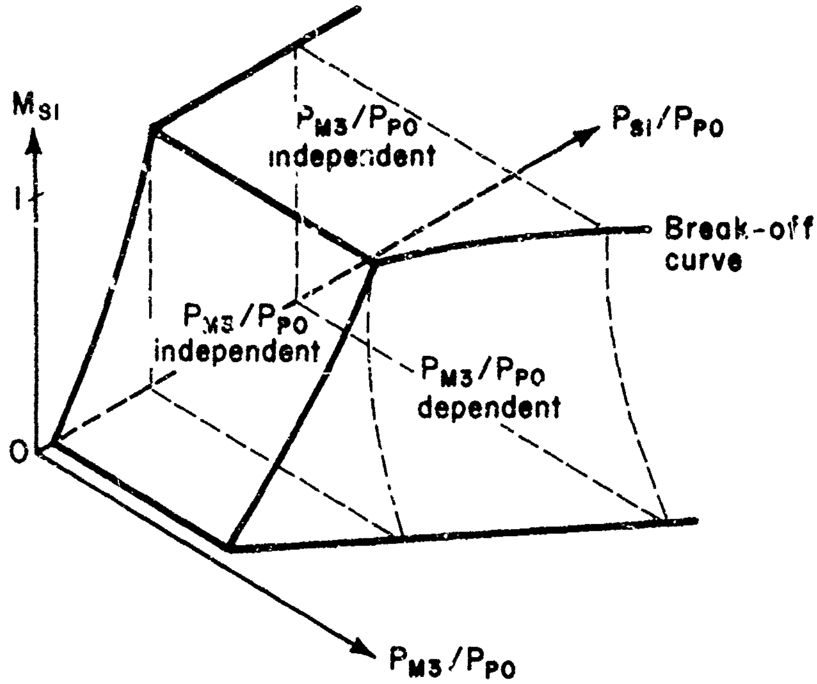
3. Based on the area ratio A_8/A_2, that pumping system with the best performance, or the smallest W_P/W_S or P_{60}/P_2 requirements, is also physically the smallest system.

4. The normal shock coefficient has a significant influence on the performance of subsonic-supersonic pumping systems and points to supersonic diffuser design as an area for careful attention.

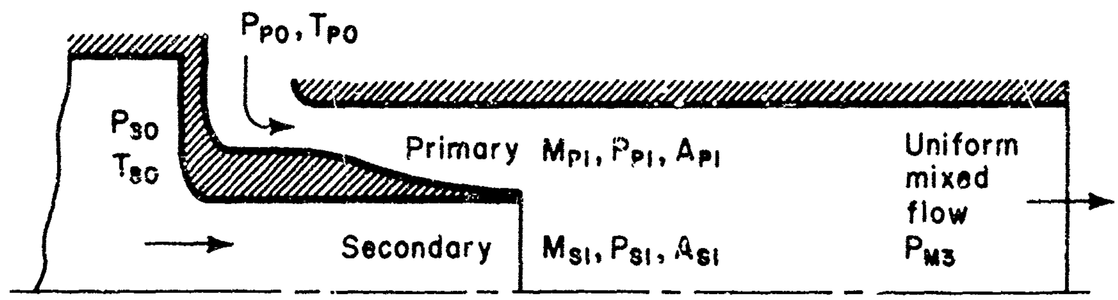
5. The comparison of a constant-area, subsonic-supersonic ejector with a constant-area supersonic-supersonic ejector on the bases of primary Mach number, M_6, and mixing tube area ratio, A_7/A_6, alone has little if any value.

4.4 COMPUTER PROGRAMS

Two computer programs were developed to conduct the foregoing optimization and system studies. The optimization program, CLGDOP, and the systems program, CLGDSP, along with sample input and output data are presented in detail in APPENDICES 7.4 and 7.5, respectively.

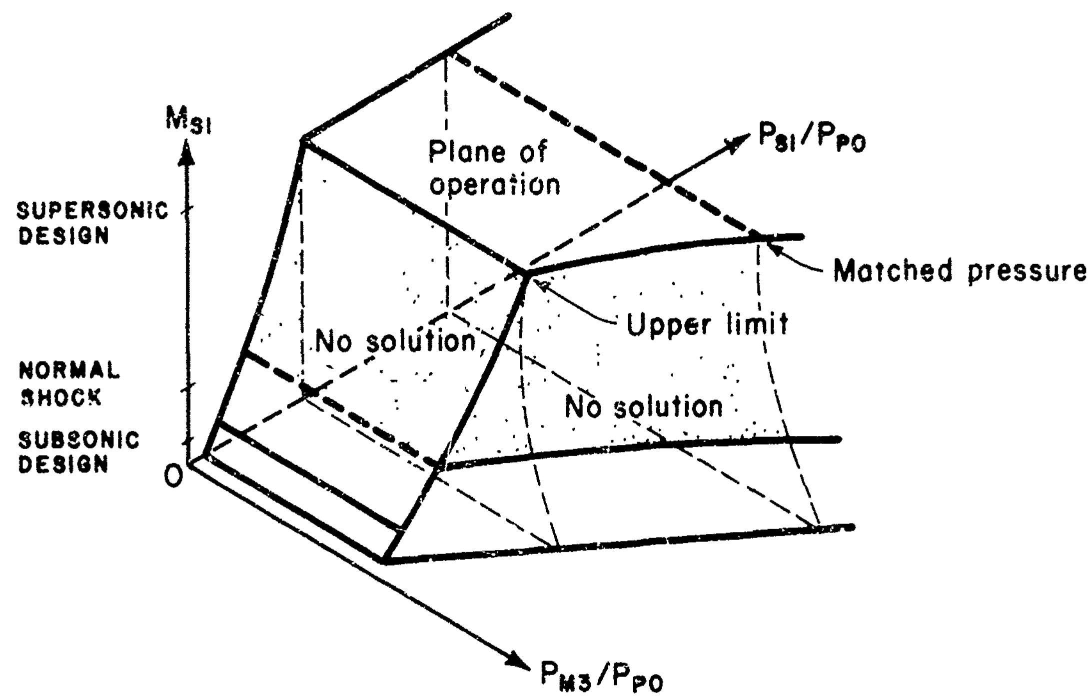


(a) Ejector Characteristic Surface

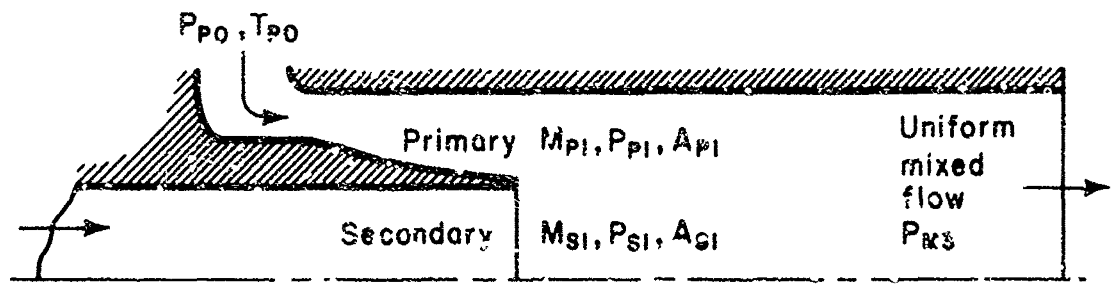


(b) Ejector Configuration and Notation

Figure 4.1-1 Constant-Area, Subsonic-Supersonic Ejector Performance Characteristics



(a) Ejector Characteristic Surface



(b) Ejector Configuration and Notation

Figure 4.1-2 Constant-Area, Supersonic-Supersonic Ejector Performance Characteristics

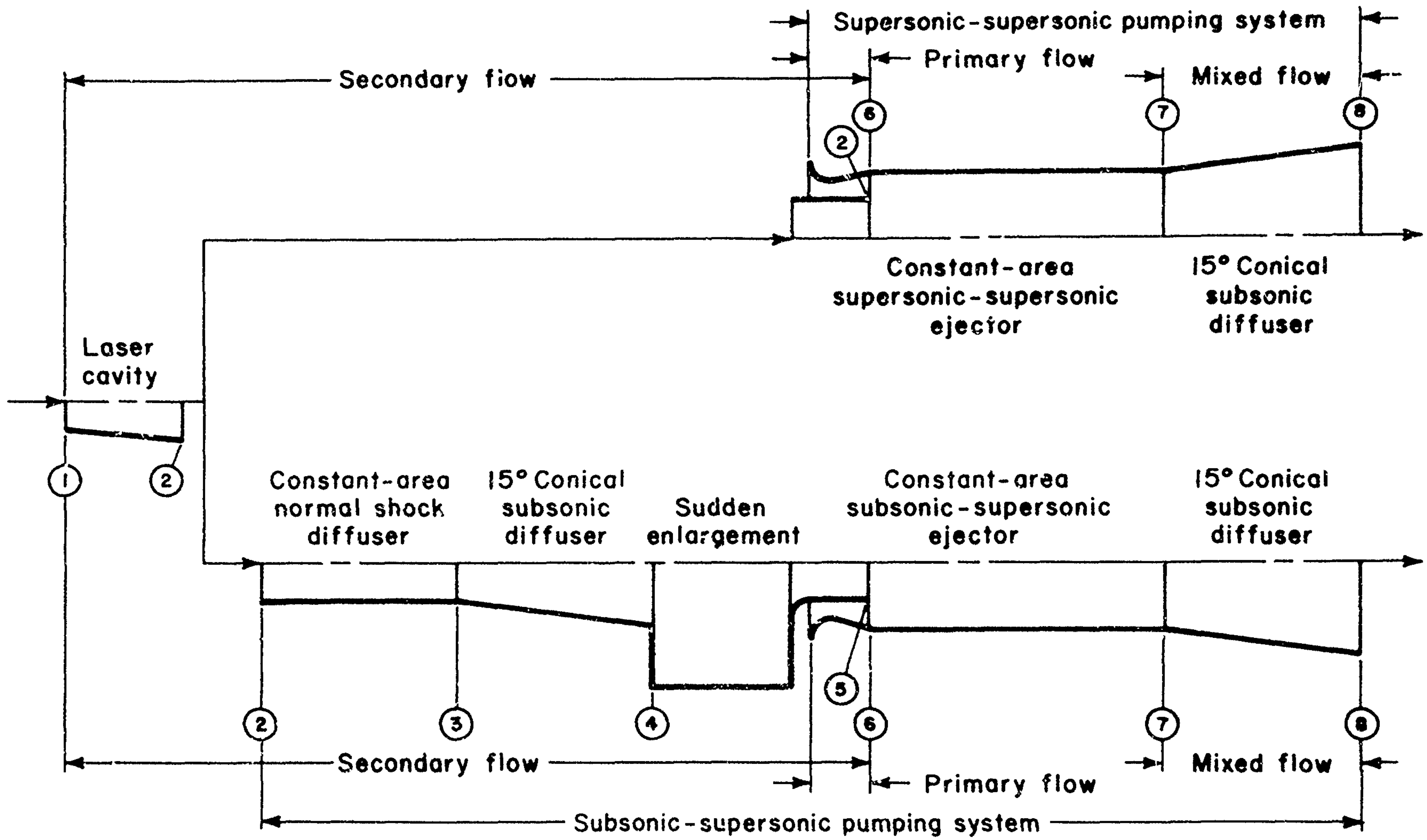


Figure 4.2-1 High-Energy, Chemical Laser System Schematic

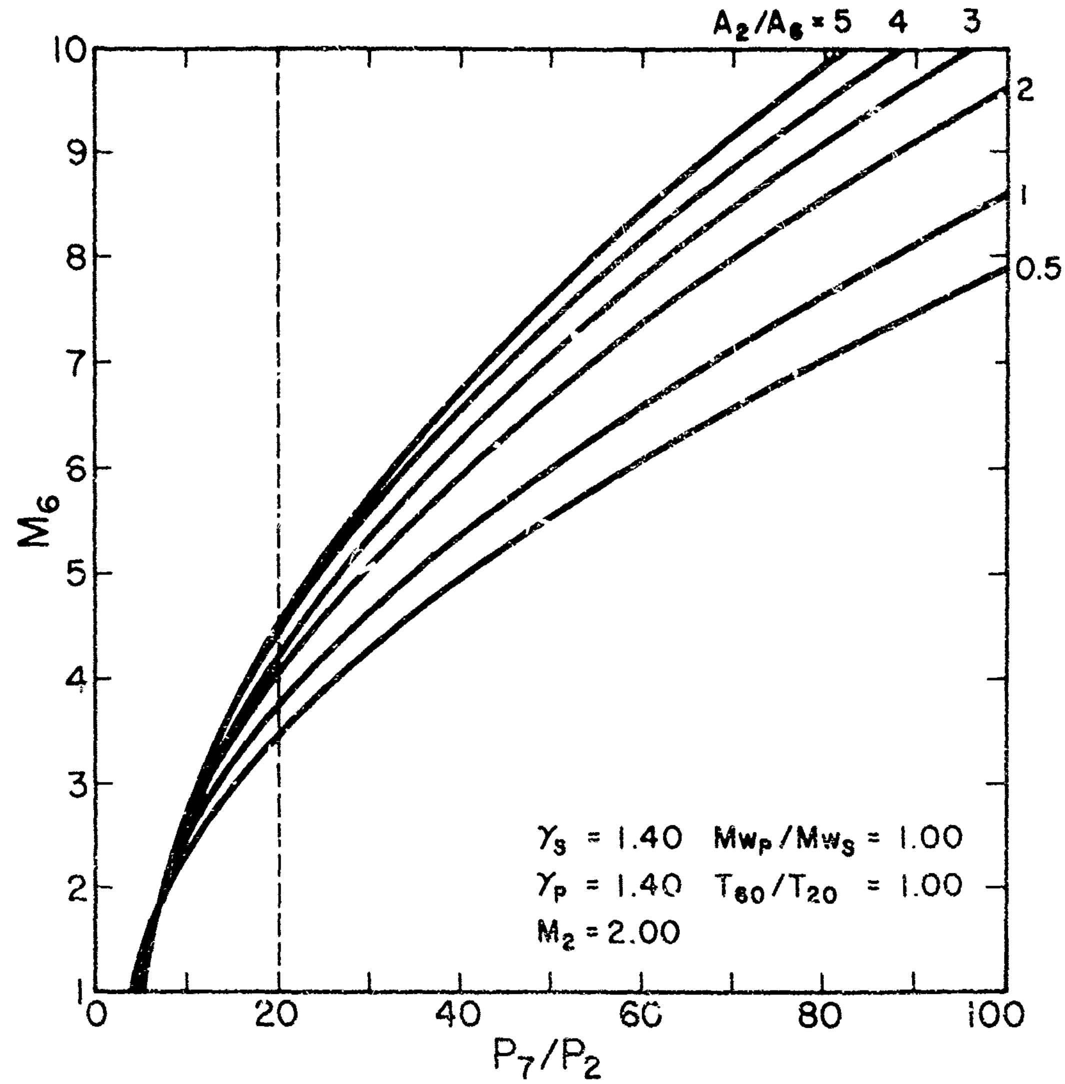


Figure 4.2-2 Typical Upper Limit Point Data for Optimization of a Supersonic-Supersonic Pumping System (M_6 vs. P_7/P_2)

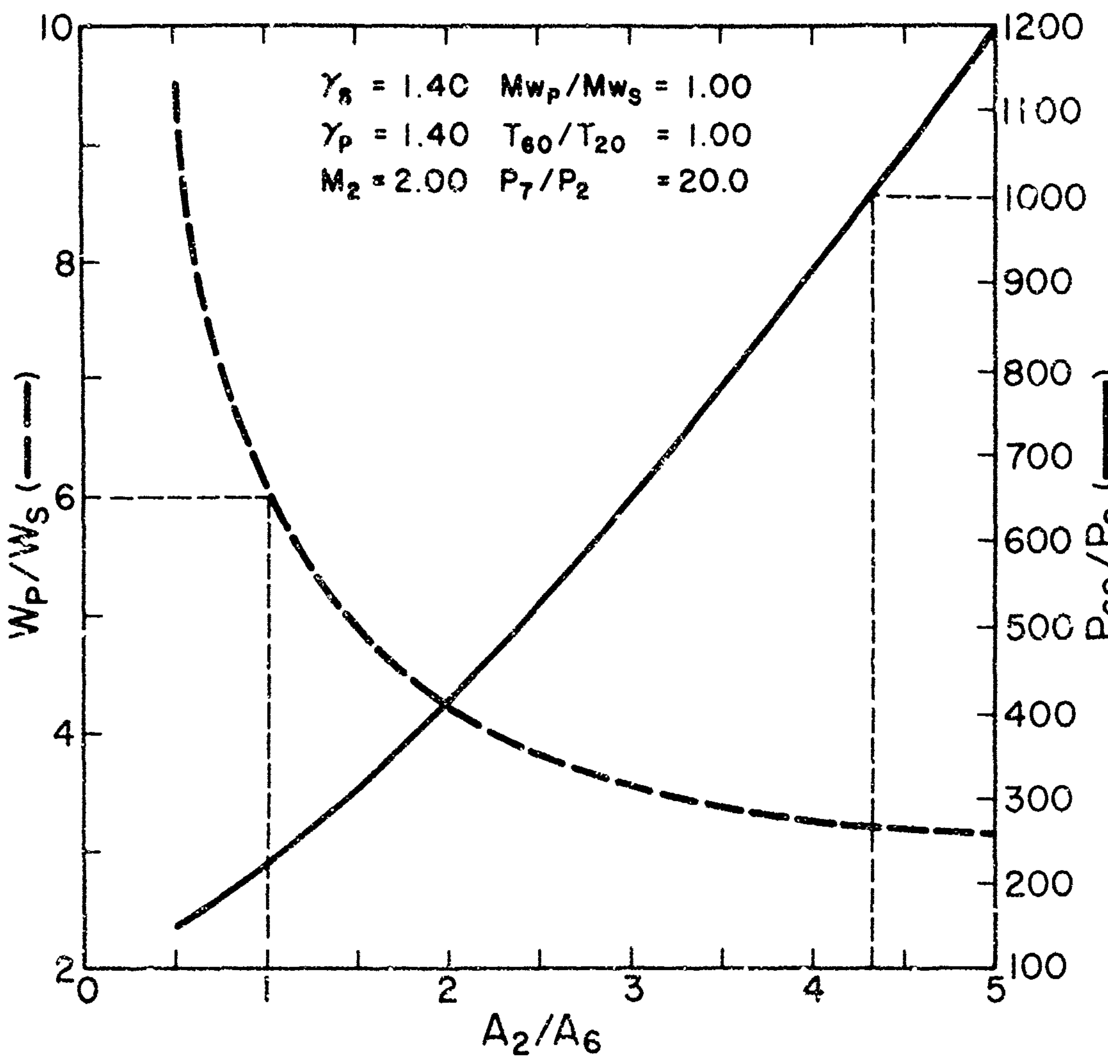


Figure 4.2-3 Typical Upper Limit Point Data for Optimization of a Supersonic-Supersonic Pumping System (W_p/W_s and P_{60}/P_2 vs. A_2/A_6)

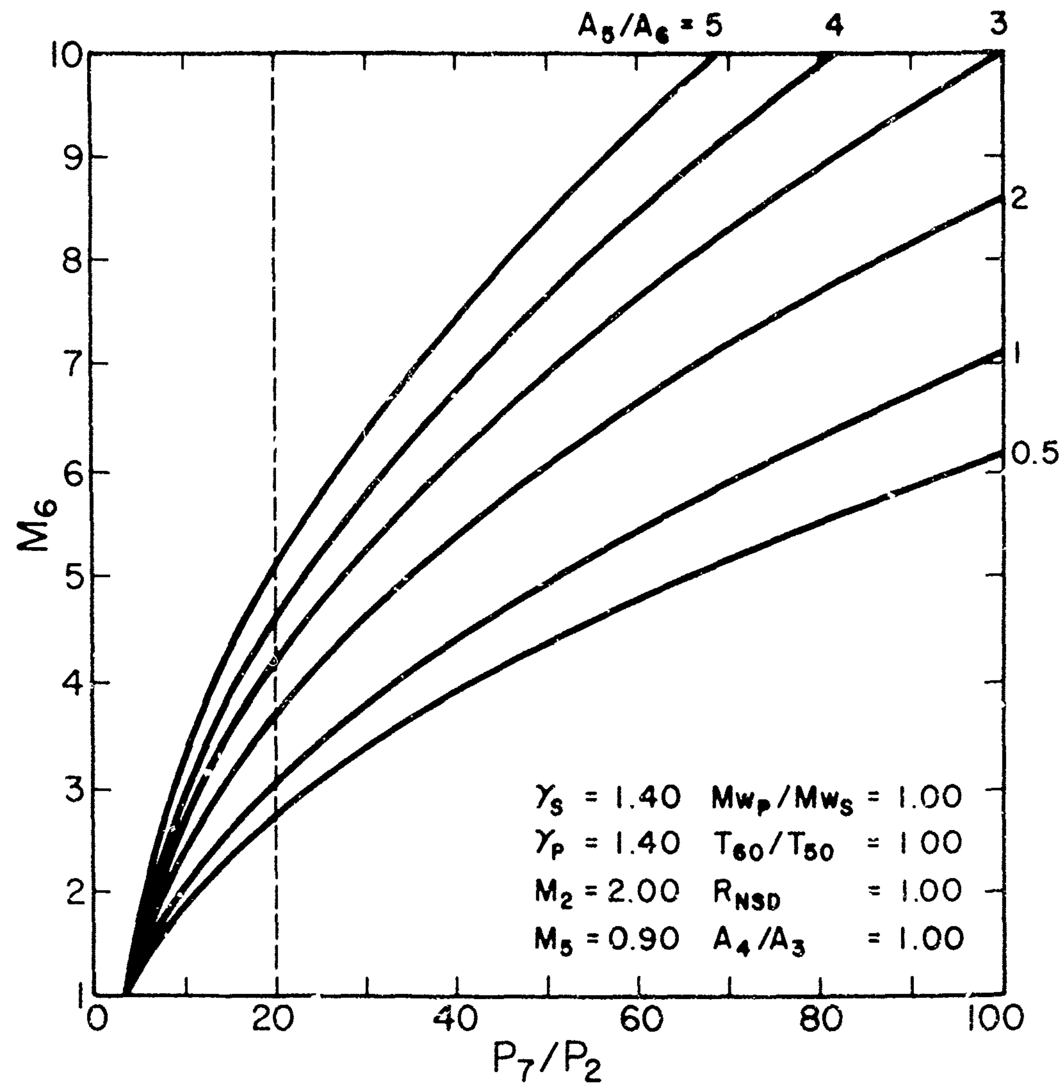


Figure 4.2-4 Typical Break-Off Data for Optimization of a Subsonic-Supersonic Pumping System (M_6 vs. P_7/P_2)

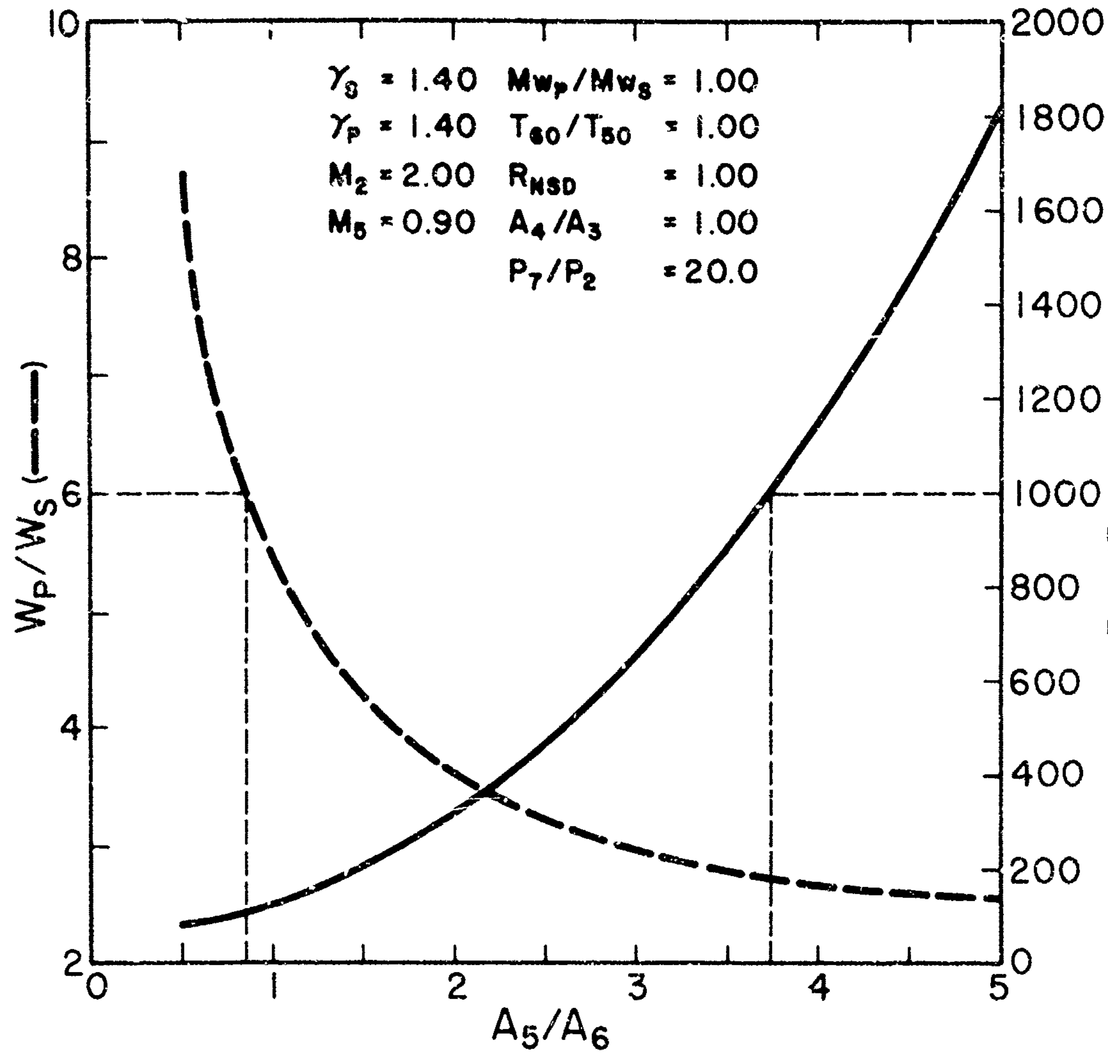


Figure 4.2-5 Typical Break-Off Data for Optimization of a Subsonic-Supersonic Pumping System (W_P/W_S and P_{60}/P_2 vs. A_5/A_6)

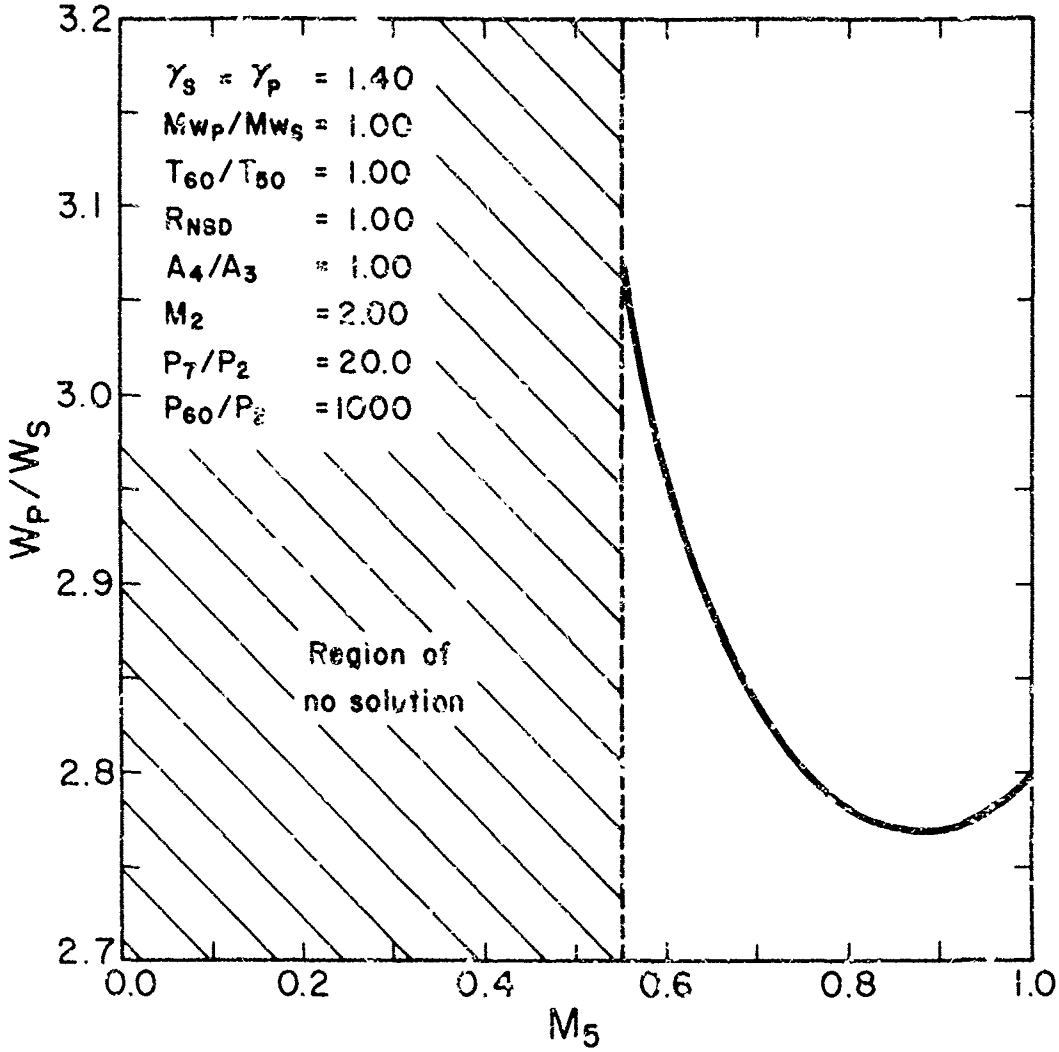


Figure 4.2-6 Typical Break-Off Data for Optimization of a Subsonic-Supersonic Pumping System (W_P/W_S vs. M_5)

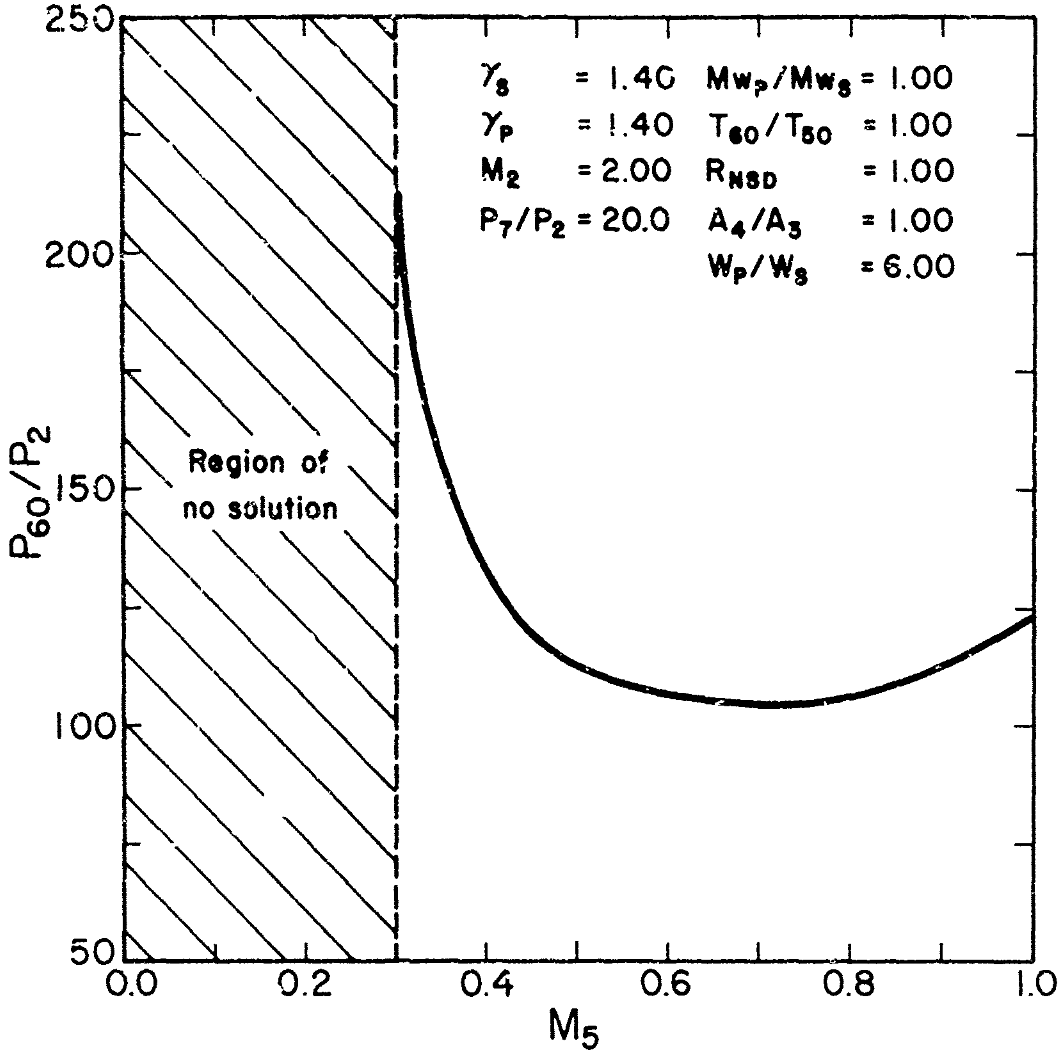


Figure 4.2-7 Typical Break-Off Data for Optimization of a Subsonic-Supersonic Pumping System (P_{60}/P_2 vs. M_5)

Table 4.3-1 Optimum Chemical Laser System Data, Case No. 1

(a) Minimum W_p/W_s

CASE NO. 1(a)

Optimum Chemical Laser System Data
for Minimum W_p/W_s

γ_S = 1 562	Mw_p/Mw_s = 1.684
γ_P = 1.340	A_8/A_7 = 2.000
M_2 = 2.180	P_{60}/P_2 = 1937

P_8/P_2 = 28.06

Supersonic-Supersonic Pumping System
at Upper Limit Point Conditions

T_{60}/T_{20} = 0.761

W_p/W_s	M_6	A_7/A_6	A_8/A_2
4.408	4.690	5.028	2.496

Subsonic-Supersonic Pumping System
at Break-Off Conditions

T_{60}/T_{50} = 0.761 A_4/A_3 = 2.000

R_{NSD}	W_p/W_s	M_6	A_7/A_6	A_8/A_2
1.00	3.747	4.734	4.828	2.125
0.85	4.792	4.858	4.136	2.614
0.75	5.777	4.955	3.695	3.079

Table 4.3-1 (Cont.)

(b) Minimum P_{60}/P_2

CASE NO. 1(b)

Optimum Chemical Laser System Data
for Minimum P_{60}/P_2

γ_S	= 1.562	Mw_P/Mw_S	= 1.684
γ_P	= 1.340	A_8/A_7	= 2.000
M_2	= 2.180	W_P/W_S	= 10.00

P_8/P_2 = 28.06

Supersonic-Supersonic Pumping System
at Upper Limit Point Conditions

T_{60}/T_{20} = 0.761

P_{60}/P_2	M_6	A_7/A_6	A_8/A_2
318.6	3.797	1.705	4.838

Subsonic-Supersonic Pumping System
at Break-Off Conditions

T_{60}/T_{50} = 0.761 A_4/A_3 = 2.000

R_{NSD}	P_{60}/P_2	M_6	A_7/A_6	A_8/A_2
1.00	110.2	2.660	1.729	4.319
0.85	174.0	3.047	1.903	4.515
0.75	270.6	3.410	2.085	4.665

Table 4.3-1 (Cont.)

(c) Minimum W_p/W_s at Matched Pressure Conditions

CASE NO. 1(c)

Optimum Chemical Laser System Data
for Minimum W_p/W_s

γ_s = 1.562	Mw_p/Mw_s = 1.684
γ_p = 1.340	A_8/A_7 = 2.000
M_2 = 2.180	P_{60}/P_2 = 1937

P_8/P_2 = 28.06

Supersonic-Supersonic Pumping System
at Matched Pressure Conditions (P_6/P_2 = 1.0)

T_{60}/T_{20} = 0.761

W_p/W_s	M_6	A_7/A_6	A_8/A_2
9.665	5.853	1.654	5.058

Table 4.3-1 (Cont.)

(d) Minimum P_{60}/P_2 at Matched Pressure Conditions

CASE NO. 1(d)

Optimum Chemical Laser System Data
for Minimum P_{60}/P_2

γ_S = 1.562	Mw_P/Mw_S = 1.684
γ_P = 1.340	A_8/A_7 = 2.000
M_2 = 2.180	W_P/W_S = 10.00

P_8/P_2 = 28.06

Supersonic-Supersonic Pumping System
at Matched Pressure Conditions (P_6/P_2 = 1.0)

T_{60}/T_{20} = 0.761

P_{60}/P_2	M_6	A_7/A_6	A_8/A_2
1836	5.807	1.623	5.209

Table 4.3-2 Optimum Chemical Laser System Data, Case No. 2

(a) Minimum W_p/W_s

CASE NO. 2(a)

Optimum Chemical Laser System Data
for Minimum W_p/W_s

$\gamma_s = 1.562$	$Mw_p/Mw_s = 1.478$
$\gamma_p = 1.340$	$A_8/A_7 = 2.000$
$M_2 = 2.230$	$P_{60}/P_2 = 1430$

$P_8/P_2 = 20.71$

Supersonic-Supersonic Pumping System
at Upper Limit Point Conditions

$T_{6c}/T_{20} = 0.807$

W_p/W_s	M_6	A_7/A_6	A_8/A_2
2.228	4.055	1.059	2.209

Subsonic-Supersonic Pumping System
at Break-Off Conditions

$T_{60}/T_{50} = 0.807$ $A_4/A_5 = 2.000$

P_{NSD}	W_p/W_s	M_6	A_7/A_6	A_8/A_2
1.00	1.968	4.476	7.000	1.952
0.85	2.559	4.596	5.838	2.375
0.75	3.108	4.690	5.128	2.771

Table 4.3-2 (Cont.)

(b) Minimum P_{60}/P_2

CASE NO. 2(b)

Optimum Chemical Laser System Data for Minimum P_{60}/P_2

$\gamma_S = 1.562$	$Mw_P/Mw_S = 1.478$
$\gamma_P = 1.340$	$A_8/A_7 = 2.000$
$M_2 = 2.230$	$W_P/W_S = 6.000$

$P_8/P_2 = 20.71$

Supersonic-Supersonic Pumping System at Upper Limit Point Conditions

$T_{60}/T_{20} = 0.807$

P_{60}/P_2	M_6	A_7/A_6	A_3/A_2
123.0	3.127	1.801	4.497

Subsonic-Supersonic Pumping System at Break-Off Conditions

$T_{60}/T_{50} = 0.807 \quad A_4/A_3 = 2.000$

R_{NSD}	P_{60}/P_2	M_6	A_7/A_6	A_8/A_2
1.00	56.38	2.223	1.844	3.951
0.85	84.21	2.568	2.047	4.160
0.75	125.7	2.894	2.262	4.323

Table 4.3-2 (Cont.)

(c) Minimum W_p/W_s at Matched Pressure Conditions

CASE NO. 2(c)

Optimum Chemical Laser System Data
for Minimum W_p/W_s

γ_s	= 1.562	Mw_p/Mw_s	= 1.476
γ_p	= 1.340	A_8/A_7	= 2.000
M_2	= 2.230	P_{60}/P_2	= 1430

P_8/P_2 = 20.71

Supersonic-Supersonic Pumping System
at Matched Pressure Conditions (P_6/P_2 = 1.0)

T_{60}/T_{20} = 0.807

W_p/W_s	M_6	A_7/A_9	A_8/A_2
3.920	5.593	2.302	3.536

Table 4.3-2 (Cont.)

(d) Minimum P_{60}/P_2 at Matched Pressure Conditions

CASE NO. 2(d)

Optimum Chemical Laser System Data
for Minimum P_{60}/P_2

$\gamma_S = 1.562$	$Mw_P/Mw_S = 1.478$
$\gamma_P = 1.340$	$A_8/A_7 = 2.000$
$M_2 = 2.230$	$W_P/W_S = 6.000$

$P_8/P_2 = 20.71$

Supersonic-Supersonic Pumping System
at Matched Pressure Conditions ($P_6/P_2 = 1.0$)

$T_{60}/T_{20} = 0.807$

P_{60}/P_2	M_6	A_7/A_6	A_8/A_2
633.0	4.934	1.677	4.955

Table 4.3-3 Optimum Supersonic Wind Tunnel Data

CASE NO. 3

Optimum Supersonic Wind Tunnel Data
for Minimum W_P/W_S

γ_S = 1.400	Mw_P/Mw_S = 1.000
γ_P = 1.400	A_8/A_7 = 2.000
M_2 = 5.000	P_{60}/P_2 = 529.1

P_8/P_2 = 67.81

Supersonic-Supersonic Pumping System
at Upper Limit Point Conditions

T_{60}/T_{20} = 1.000

W_P/W_S	M_S	A_7/A_6	A_8/A_2
1.810	2.063	8.758	2.258

Subsonic-Supersonic Pumping System
at Break-Off Conditions

T_{60}/T_{50} = 1 000 A_4/A_3 = 2.000

R_{NSD}	W_P/W_S	M_6	A_7/A_6	A_8/A_2
1.00	1.349	2.811	4.450	1.700
0.85	1.852	2.918	3.669	2.130
0.75	2.336	3.001	3.217	2.549

5.0 CONCLUSIONS

As a result of this preliminary theoretical and experimental analysis of the constant-area, supersonic-supersonic ejector, the following conclusions may be drawn.

1. A one-dimensional theory was developed which predicts the performance characteristics of all constant-area, supersonic-supersonic ejector configurations.

2. Due to the simplified analysis of the constant-area, mixing section and inviscid interaction region, the present one-dimensional theory is particularly well-suited to parametric evaluations of constant-area, supersonic-supersonic ejector performance.

3. The present one-dimensional theory predicts maximum compression ratios which are 15 to 21 percent greater than experimental measurements.

4. The constant-area, supersonic-supersonic ejector is particularly susceptible to secondary flow separation which requires a more sophisticated method of analysis than the present one-dimensional theory.

5. Continued experimentation is needed to:

   a) Establish a sufficient length for constant-area, supersonic-supersonic ejector mixing tubes.

   b) Obtain supersonic-supersonic ejector data over a wide range of operation, particularly under simulated high-energy, chemical laser system conditions.

   c) Verify the present one-dimensional theory for plane, two-dimensional ejector configurations which are more consistent with current high-energy, chemical laser designs.

d) Develop more advanced theoretical models, including a "two-shock" model, through flow visualization studies of the mixing and interaction phenomena.

e) Evaluate the effects of variable mixing tube wall profiles which have proved advantageous in subsonic-supersonic ejector development.

6. The constant-area, supersonic-supersonic ejector is an extension of the constant-area, subsonic-supersonic ejector with similar characteristic surfaces.

7. The constant-area, subsonic-supersonic and supersonic-supersonic ejectors must be compared on an optimum, overall pumping system basis.

8. Present one-dimensional theories for both the constant-area, subsonic-supersonic and supersonic-supersonic ejectors may be incorporated into a single high-energy, chemical laser system optimization procedure.

9. Conclusions as to the relative performance of optimum subsonic-supersonic and supersonic-supersonic pumping systems are included in Section 4.3; but in summary, a supersonic-supersonic pumping system has the potential for improved performance over that of a subsonic-supersonic pumping system on the basis of mass flow ratio and primary stagnation pressure; however, this depends on

a) The high-energy chemical laser system constraints,

b) The source of disagreement between the present one-dimensional, supersonic-supersonic ejector theory and experiment as noted in item 3, preceding, and

c) An adequate solution to the secondary flow separation problems encountered during high compression ratio operation of the constant-area, supersonic-supersonic ejector.

6.0 REFERENCES

1. Addy, A. L., and Mikkelsen, C. D., "An Investigation of Gas-Dynamic Flow Problems in Chemical Laser Systems," Department of Mechanical and Industrial Engineering, University of Illinois at Urbana-Champaign, Report No. UILU-ENG-74-4009 (1974).

2. Spiegel, J. M., Hofstetter, R. U., and Kuehn, D. M., "Applications of Auxiliary Air Injectors to Supersonic Wind Tunnels," NACA RM A53I01 (1953).

3. Hunczak, H. R., and Rousso, M. D., "Starting and Operating Limits of Two Supersonic Wind Tunnels Utilizing Auxiliary Air Injection Downstream of the Test Section," NACA TN 3262 (1954).

4. Hasel, L. E., and Sinclair, A. R., "A Preliminary Investigation for Improving the Pressure-Recovery Characteristics of Variable-Geometry Supersonic-Subsonic Diffuser Systems," NACA RM L57H02 (1957).

5. Fabri, J., and Paulon, J., "Theory and Experiments on Supersonic Air-to-Air Ejectors," NACA TM 1410 (1958).

6. Fabri, J., and Siestrunck, R., "Supersonic Air Ejectors," Advances in Applied Mechanics, New York, N.Y., Academic Press, Vol. V, pp. 1-34 (1958).

7. Crocco, L., "One-Dimensional Treatment of Steady Gas Dynamics," Fundamentals of Gas Dynamics," Emmons, H. W., Editor, Princeton, N.J., Princeton University Press, Vol. III, pp. 272-293 (1958).

8. Addy, A. L., "On the Steady State and Transient Operating Characteristics of Long Cylindrical Shroud Supersonic Ejectors (With Emphasis on the Viscous Interaction Between the Primary and Secondary Streams)," Ph.D. Thesis, Department of Mechanical Engineering, University of Illinois, Urbana (1963).

9. Chow, W. L., and Addy, A. L., "Interaction between Primary and Secondary Streams of Supersonic Ejector Systems and their Performance Characteristics," AIAA Journal, 2(4):686-695 (1964).

10. Addy, A. L., "The Analysis of Supersonic Ejector Systems," Supersonic Ejectors, AGARDograph No. 163, pp. 31-101 (1972).

11. Addy, A. L., "The Analysis of Supersonic Ejector Systems," Ejectors, von Karman Institute, Lecture Series 79 (1975).

12. Howlett, L. D., and Chow, W. L., "A Study of Nozzle and Ejector Flow Problems by the Method of Integral Relations," NASA CR-128066 (1972).

13. Hickman, K. D., Hill, P. G., and Gilbert, G. B., "Analysis and Testing of Compressible Flow Ejectors with Variable Area Mixing Tubes," Journal of Basic Engineering, 94(2):407-416 (1972).

14. Hedges, K. R., and Hill, P. G., "Compressible Flow Ejectors, Part I - Development of a Finite-Difference Flow Model," ASME Paper No. 74-FE-1 (1974).

15. Hedges, K. R., and Hill, P. G., "Compressible Flow Ejectors, Part II - Flow Field Measurements and Analysis," ASME Paper No. 74-FE-2 (1974).

16. Zukoski, E. E., "Turbulent Boundary-Layer Separation in Front of a Forward-Facing Step," AIAA Journal, 5(10):1746-1753 (1967).

17. Patterson, G. N., "Modern Diffuser Design," Aircraft Engineering, 9(9):267-273 (1938).

18. Henry, J. R., Wood, C. C., and Wilbur, S. W., "Summary of Subsonic-Diffuser Data," NACA RM L56F05 (1956).

7.0 APPENDICES

7.1 A LITERATURE SURVEY OF EJECTOR SYSTEMS AND RELATED TOPICS

1. "Practical Application to Pumps of Small Lifts, Ventilation, Etc.," Engineering Record, 400-401 (November 19, 1892).

2. "Ejector Condensers vs. Jet Condensers and Air Pumps," Practical Engineer (November 26, 1897).

3. Rateau, A., "The Theory of the Ejector-Condenser and Experiments with a New Type," Revue de Mécanique (June 1902).

4. Mechanical Engineer (England), (June 5, 1908).

5. Bullock, S., "Ejector Condensers," Iron & Coal Trades Review (April 26, 1912).

6. Balch, L. R., "Tests of a Jet Pump," Bulletin of the University of Wisconsin, No. 596, 15 pp. (1914).

7. Delaporte, M., "The Breguet Ejectair," Journal of the American Society of Naval Engineers (May 1914).

8. Delas, A., "General Considerations on Condenser Air-Pumps," Memoires de la Société des Ingenieurs Civils de France (May 1914).

9. Witz, A., "Steam Ejector Condensors," Le Technique Moderne (July 1, 1914).

10. Verdam, N.C.H., "De lucht-ejecteur systeem Westinghouse-Leblanc," Ingenieur (November 18, 1916).

11. "Methods for Producing High Vacuum," Transactions of the North-East Coast Institution of Engineers & Shipbuilders (February 1918).

12. Conge, L., "Les éjecteurs extracteurs d'air," Revue Générale de l'Eléctricité, 4(17):629-632 (1918).

13. Morgan, D.W.R., "Recent Developments in Condensers," Electrical World (August 3, 1918).

14. Wheeler, F. R., "Air Pumps for Condensing Equipment," Mechanical Engineering, 41(12):926-930 (1919).

15. Lashinger, E. J., "Air Ejectors - Theory and Design," Journal of the South Aftican Institution of Engineers, 18(6):89-91 (1920).

16. Meyer, E., "The Theory of Steam-Jet Air Pumps," Schiffbau, 22(4):76-81 (1920).

17. Taylor, D. M., "Steam-Jet Air Pumps for Condensers," Power, 51(25):995-999 (1920).

18. Jauch, L., "Recent Improvements in Condensing Apparatus for Steam Engines," Chaleur et Industree, 2(16):501-508 (1921).

19. Hepburn, H. A., "The Gaseous Fluid Ejector," Engineer, 134(3486, 3487):401-402, 429-430 (1922).

20. Hoefer, K., "Investigations of Condensing Air Pumps," Forschungsarbeiten auf dem Gebiete des Ingenieur-Wesens, No. 253, 92 pp. (1922).

21. Blaum, R., "A New Air Pump for Turbine Steamers," Zeitschrift des vereines deutscher Ingenieure, 67(39,40):956-957 (1923).

22. Heuser, L., and Finzel, K., "Steam Ejectors and Water-Jet Pumps in Condenser Plants," Schiffbau, 24(51,52):785-791 (1923).

23. Muller, F., "The Steam-Jet Apparatus as Air Pump for Turbine Condensers," Schiffbau, 24(30,31):486-489 (1923).

24. "L'Ejecteur-Air Condenseur," Génie Civil, 84(10):234-235 (1924).

25. "The Steam-Jet Vacuum Ejector," Mechanical World, 76(1973,1974): 264-265, 277-278 (1924).

26. "Water and Steam-Jet Air Pumps for Surface Condensers Especially on Board Ships," Zeitschrift des vereines deutscher Ingenieure, 68(12): 288-292 (1924).

27. Von Le Juge, S., "Water- vs. Steam-Jet Air Pumps," Wärme, 47(3): 21-23 (1924).

28. Carleton, H. E., "Economy of the Steam Jet Air Pump," Power Plant Engineering, 29(11):595 (1925).

29. Ernsberger, M. C., "A Steam Ejector for Pumping Low Pressure Steam," Sibley Journal of Engineering, 39(6):357-358 (1925).

30. Johnstone-Taylor, F., "Pneumatic Ejectors," Mechanical World 78(2020):224-226 (1925).

31. Kothny, G. L., "New Developments in High Vacuum Apparatus," Society of Naval Architects & Marine Engineers, Advance Paper No. 1 for meeting November 12, 1925; Abstract, Marine Engineering & Shipping Age, 30(12):689-690 (1925).

32. Lamb, N. A., "Steam Ejectors in Condensers for High Vacua," World Power, 4(22):200-205 (1925).

33. McNair, D. G., "The Ejector Air Pump," Power Engineer, 20(235): 367-370 (1925).

34. Smith, J. H., "The Steam-Jet Condensing-Type Vacuum Pump," Electric Journal, 22(1):17-23 (1925).

35. Brada, T., "Basic Theory of Thermal Compressors," Chaleur et Industree, 7(80):673-678 (1926).

36. Colburn, C. E., "Hints on the Practical Operation of Air Ejectors," Power, 63(11):410-411 (1926).

37. Morgan, D.W.R., "Three-Stage Air Ejector Uses Less Steam," Power, 64(4):127-128 (1926).

38. McNulty, J. W., "Air Ejectors for Industrial Applications," Electric Journal, 24(10):505-506 (1927).

39. Third, A. D., "The Air Ejector," Journal of the Royal Technological Society, 4:84-103 (1927).

40. McNair, D. G., "Steam-Jet Air Ejectors for High Vacuum," Mechanical World, 84(2177):267-270 (1928).

41. "Ejectors Monopolize High Vacuum Field," Power Plant Engineering, 33(15):853-855 (1929).

42. Maunder, F. J., "Condensers, Air-Pumps, and Ejectors," Mechanical World, 85(2204):294-295 (1929).

43. "Calculation of Ejectors Employed in Naval Construction for Scavenging of Foul Air," Bulletin Technique du Bureau Veritas, 12(9):184-186 (1930).

44. McNair, D. G., "High-Vacuum Ejectors," Power Engineer, 26(306): 330-332 (1931).

45. "Steam-Jet Ejectors for Steam Condensers," AEG Progress, 3:54-55 (1933).

46. Watson, F.R.B., "Production of Vacuum in Air Tank by Means of Steam Jet," Proceedings of the Institution of Mechanical Engineers, 124: 231-265, 266-300 (1933); Engineering, 135(3502,3503).230-232, 255-257, 262-265 (1933); Engineer, 155(4024):192-194, 198 (1933).

47. "Ejector-Pump Installation," Engineering, 142(3679):80 (1936).

48. Scott, A. W., and Jamieson, J., "Nozzle Effects in Air Ejector," Journal of the Royal Technical College, 3(4):627-635 (1936).

49. Simon, W., "Dampf- und Luftstrahlsauger im Kesselhaus," Wärme, 59(41):659-663 (1936).

50. "Cinder-Recovery Plant for Boiler Installations," Engineering, 144(3733):123-124 (1937).

51. Dowson, R., "Performance of Single-Stage Steam Jet Operated Ejectors," 164(4274,4275,4277):650-652, 680-681, 747 (1937).

52. Watson, J. D., "Industrial Applications of Jet Condenser," Steam Engineer, 6(68,69):343-345, 386-388, 394 (1937).

53. Fluefel, G., "Berechnung von Strahlapparaten," VDI Forschungsheft, 10(395), 21 pp. (1939).

54. Lidiak, J. P., "Ejectors Beat Air Pumps," Power, 83(8):72-74 (1939).

55. Tanishita, I., "Studies on Steam Ejector," Bulletin of the Institute of Physical and Chemical Research, 18(4):293-320 (1939).

56. Work, L. T., and Haedrich, V. W., "Performance of Ejectors," Industrial & Engineering Chemistry, 31(4):407-486 (1939).

57. Kravath, F. F., "Venturi Ejector for Handling Air," Heating & Ventilation, 37(6,8):17-21, 46-49 (1940).

58. Work, L. T., and Miller, A., "Factor C in Performance of Ejectors as Function of Molecular Weights of Vapors," Industrial & Engineering Chemistry, 32(9):1241-1243 (1940).

59. Bruce, R., "Alexander Morton and Ejector Condenser," Engineer, 171(4441):126 (1941).

60. Frey, O., "On Steam-Jet Air Ejectors," Brown Boveri Revue, 28(11): 382-383 (1941).

61. Finn, P. J., "Flow Losses in, and Design Data for, Compressed Air Operated Venturi Ejectors and Blowers," Journal of the South African Institution of Engineers, 41(3):70-86, 86-94 (1942); 43(1):16-21 (1943); 43(3):93 (1943); Mechanical World, 113(2940):494-496 (1943).

62. Hatt, H. A., "Notes on Maintenance of Pneumatic Ejectors," Journal of the Junior Institution of Engineers, 52(2):276-279 (1942).

63. Keenan, J. H., and Neumann, E. P., "Simple Air Ejector," Journal of Applied Mechanics, 9(2):A75-A81 (1942).

64. "Duplex Air Ejector for Surface Condensing Plant," Beama Journal, 50(74):257-258 (1943).

65. Engdahl, R. B., and Holton, W. C., "Overfire Air Jets," Transactions of the ASME, 65(7):741-751, 751-754 (1943).

66. Frenau, P., and Ross, E. G., "Operation and Maintenance of Steam-Jet Ejectors," Nautical Gazette, 133(12):38-41, 50, 66-69, 80-81, 91-92 (1943).

67. Goff. J. A., and Coogan, C. H., "Some Two-Dimensional Aspects of Ejector Problem," Journal of Applied Mechanics, 9(4):A151-A154 (1942); 10(2):A114-A115 (1943).

68. "Venturi Ejectors and Blowers," Mechanical World, 116(3026):712-713, 715 (1944).

69. Bean, D. R., "Note on Theory of Steam Ejector," Engineer, 180(4675): 131-132 (1945).

70. Elrod, H G., "Theory of Ejectors," Journal of Applied Mechanics, 12(3):A170-A174 (1945); 13(2):A162-A165 (1946).

71. Freneau, P., "Know Steam-Jet Air Ejectors and They'll Serve You Well," Power, 89(6):372-374 (1945).

72. Freneau, P., "Multi-Stage Ejectors for High-Vacuum Performance," Power, 89(7):443-445, 488a-488b (1945).

73. Gordon, S. M., "Factors in Replacing RDV Pumps with Steam Jet Ejectors," Blast Furnace & Steel Plant, 33(2):256-257, 272 (1945).

74. Mansa, J. L., "Ejector Test Station," Engineers' Digest, 6(4):108-109 (1945); (American Edition) 2(6):290-291 (1945).

75. Scott, W. P., "Steam Jet Air Ejector," Transactions of the Institute of Marine Engineers, 57(3):51-56 (1945).

76. Crownover, J. C., "Steam-Jet Ejectors - Their Selection and Operation," Combustion, 17(7):24-31 (1946).

77. Darling, C. S., "Use of Ejector Condenser," Mechanical World, 120(3128):655-657 (1946).

78. Freneau, P., "Condenser and Steam-Jet Air Ejector: Team for Maintaining Exhaust Vacuum," Power, 90(2):85-88 (1946).

79. McClintock, F. A., and Hood, J. H., "Aircraft Ejector Performance," Journal of Aeronautical Sciences, 13(11):559-568 (1946).

80. Meckley, W. O., "Exhaust Ejector Improves both Turbo Cooling and Propulsion," Aviation, 45(3):74-75, 150-151 (1946).

81. "Design of Injectors for Low-Pressure Air Flow," Heating & Ventilation, 44(7):82-94 (1947).

82. Clegern, W. A., "New Ejector Device Uses Exhaust Energy for Engine Cooling," Automotive & Aviation Industries, 96(8):24-27 (1947).

83. Freneau, P., "Steam-Jet Air Evacuators Make Vacuum During Power Plant Starting Periods," Power, 91(3):162-165 (1947).

84. Freneau, P., Kelso, G., and Hoge, A. W., "Application of Steam-Jet Ejectors in Houdry Fixed-Bed Catalytic Cracking Process," Transactions of the ASME, 69(1):69-79 (1947).

85. McRoberts, L., "Foresee Wider Use of Exhaust Jet Cooling," Automotive Industries, 97(2):34-35, 74, 76, 80, 82 (1947).

86. Woodman, W. C., "Rotary or Steam-Jet Air Pumps," Power, 92(8): 470-473, 510b (1948).

87. Berman, L. D., "Steam Jet Ejector Characteristics," Engineers' Digest, 11(5):169-171 (1950).

88. Binder, R. C., "Measurement of Flow Rate in Saturated-Air Test for Steam-Jet Ejectors," ASME, Advance Paper No. 50-A-47 for meeting November 26-December 1, 1950, 6 pp.

89. Johannesen, N. H., "Design of Ejectors," Ingenioren, 59(41):831-835 (1950).

90. Johannesen, N. H., "Ejektorers Anvendelsesomrader," Ingenioren, 59(20):568-589 (1950).

91. Kastner, L. J., and Spooner, J. R., "Investigation of Performance and Design of Air Ejector Employing Low-Pressure Air as Driving Fluid," Proceedings of the Institution of Mechanical Engineers, 162(2):149-159 (1950).

92. Keenan, J. H., Neumann, E. P., and Lustwerk, F., "Investigation of Ejector Design by Analysis and Experiment," Journal of Applied Mechanics, 17(3):299-309 (1950); 18(1):117 (1951).

93. "Vacuum - Magic Hat of Industry," Compressed Air Magazine, 56(6): 142-149 (1951).

94. Ellis, C. W., Hollister, D. P., and Sargent, A. F., Jr., "Preliminary Investigation of Cooling-Air Ejector Performance at Pressure Ratio from 1 to 10," NACA RM E51H21 (1951).

95. Evans, W. R., "Cooling with Steam," Southern Power & Industry, 69(7):42-45 (1951).

96. Holton, W. C., "Effect of Molecular Weight of Entrained Fluid on Performance of Steam-Jet Ejectors," Transactions of the ASME, 73(7):905-910 (1951).

97. Holton, W. C., and Schultz, E. J., "Effect of Temperature of Entrained Fluid on Performance of Steam-Jet Ejectors," Transactions of the ASME, 73(7):911-913 (1951).

93. Knoerschild, E. M., "The Design and the Performance Calculation of Ejectors and Aspirators," Wright Air Development Center, Air Force Technical Report No. 6673 (1951).

99. Kochendorfer, F. D., and Rousso, M. D., "Performance Characteristics of Aircraft Cooling Ejectors having Short Cylindrical Shrouds," NACA RM E51E01 (1951).

100. Levine, A., "Modernization of Tugboat Power Plants," Marine Engineering & Shipping Review, 56(5):57-61 (1951).

101. Stinson, L. S., "Keep Your Steam Ejectors Up to Snuff," Power Engineering, 55(7):87-88, 90 (1951).

102. Towle, H. C., and Judd, F.V.H., "Ejectors for Cooling Turbojet Installation," Aeronautical Engineering Revue, 10(9):20-24 (1951).

103. White, J. C., "Injector Type Steam Jets Solve Heating System Problem," National Engineer, 55(1):15, 24 (1951).

104. Alexander, L. G., "Turbulent Transfer of Momentum, Heat, and Mass in Jet Ejector," Ohio State University Engineering Experiment Station, Bulletin No. 149 (1952).

105. Greathouse, W. K., and Hollister, D. P., "Preliminary Air-Flow and Thrust Calibrations of Several Conical Cooling-Air Ejectors with a Primary to Secondary Temperature Ratio of 1.0, II - Diameter Ratios of 1.06 and 1.40," NACA RM E52F26 (1952).

106. Jones, D. E., "Passenger Car Heating and Air Conditioning," Engineering Journal, 35(4):332-338 (1952).

107. Weinberg, S., "Heat Transfer to Low Pressure Sprays of Water in Steam Atmosphere," Proceedings of the Institution of Mechanical Engineers, 1B(6):240-253, 253-258 (1952); Heating & Air Treatment Engineer, 16(1,2):17-25, 45-53 (1953).

108. Fabri. J., Le Grives, F., and Siestrunck, R., "Etude aérodynamique des trompes supersoniques," Janrbuch der Wissenschaftlichen Gesellschaft fuer Luftfahrt, 106-101 (1953).

109. Fondrk, V. V., "Multistage Ejectors for High Vacuum," Chemical Engineering Progress, 49(1):3-7 (1953).

110. Greathouse, W. K., and Hollister, D. P., "Air-Flow and Thrust Characteristics of Several Cylindrical Cooling-Air Ejectors with a Primary to Secondary Temperature Ratio of 1.0," NACA RM E52L24 (1953).

111. Hings, D. C., "Glass Pipe Line Ejectors," Industrial Chemist, 29(346):537-538, 544 (1953).

112. Jackson, D. H., "Corrosion Problems in Steam-Jet Vacuum Equipment," Chemical Engineering Progress, 49(2):102-104 (1953).

113. Medici, M., "Design of Jet Ejectors," Engineers' Digest, 14(2): 51-53 (1953).

114. Moos, H. R., "Analytical and Experimental Study of Low Pressure Air Ejector Pumps," SAE, paper for meeting December 14, 1953, 9 pp.

115. Peterson, J., "Steam Jets Efficiently Remove Dust from Open Hearth Furnace Flues," Journal of Metals, 5(6):794-795 (1953).

116. Plank, R., "Strahlkaeltemacshinen," Ingenieur, 65(51):CH113-CH117 (1953).

117. Reshotko, E., "Performance Characteristics of a Double-Cylindrical-Shroud Ejector Nozzle," NACA RM E53H28 (1953).

118. Spiegel, J. M., Hofstetter, R. U., and Kuehn, D. M., "Applications of Auxiliary Air Injectors to Supersonic Wind Tunnels," NACA RM A53I01 (1953).

119. Stewart, P. B., and Kreita, F., "What's Ahead for Jet Engines and Rocket Motors in Process Units?" Chemical Engineering, 60(9): 208-211 (1953).

120. Zimmerman, L., "Graphisches Berechnungsverfahren fuer mehrstufige Damphstrahlapparate," Chemie-Ingenieur-Technik, 25(11):665-671 (1953).

121. Allen, J. L., "Pumping Characteristics for Several Simulated Variable-Geometry Ejectors with Hot and Cold Primary Flow," NACA RM E54G15 (1954).

122. Ciopluch, C. C., and Fenn, D. B., "Experimental Data for Four Full-Scale Conical Cooling-Air Ejectors," NACA RM E54F02 (1954).

123. Gorton, G. C., "Pumping and Drag Characteristics of an Aircraft Ejector at Subsonic and Supersonic Speeds," NACA RM E54D06 (1954).

124. Greathouse, W. K., "Performance Characteristics of Several Full-Scale Double-Shroud Ejector Configurations over a Range of Primary Gas Temperatures," NACA RM E54F07 (1954).

125. Greathouse, W. K., "Preliminary Investigation of Pumping and Thrust Characteristics of Full-Size Cooling-Air Ejectors at Several Exhaust-Gas Temperatures," NACA RM E54A18 (1954).

126. Hearth, D. P., and Valerino, A. S., "Thrust and Pumping Characteristics of a Series of Ejector-Type Exhaust Nozzles at Subsonic and Supersonic Flight Speeds," NACA RM E54H19 (1954).

127. Hunczak, H. R., and Rousso, M. D., "Starting and Operating Limits of Two Supersonic Wind Tunnels Utilizing Auxiliary Air Injection Downstream of the Test Section," NACA TN 3262 (1954).

128. Huntley, S. C., and Yanowitz, H., "Pumping and Thrust Characteristics of Several Divergent Cooling-Air Ejectors and Comparison of Performance with Conical and Cylindrical Ejectors," NACA RM E53J13 (1954).

129. Kochendorfer, F. D., "Effect of Properties of Primary Fluid on Performance of Cylindrical Shroud Ejectors," NACA RM E53L24a (1954).

130. Kochendorfer, F. D., "Note on Performance of Aircraft Ejector Nozzles at High Secondary Flows," NACA RM E54F17a (1954).

131. Messina, P., Brown, J. J., and Bohnlofink, J., "How to Check Your Jet Utilities," Chemical Engineering, 61(1):161-164 (1954).

132. Rolls, L. S., and Havill, C. D., "An Evaluation of Two Cooling-Air Ejectors in Flight at Transonic Speeds," NACA RM A54A05 (1954).

133. Spalding, D. B., "Compressible Flow of Semi-Perfect Gas," Engineering, 117(4616):777-781 (1954); Journal of the American Society of Naval Engineers, 66(4):992-1004 (1954).

134. Useller, J. W., Huntley, S. C., and Fenn, D. B., "Combined Compressor Coolant Injection and Afterburning for Turbojet Thrust Augmentation," NACA RM E54G08 (1954).

135. Fabri, J., and Siestrunck, R., "Etude des divers regimes d'ecoulement dans l'elargissement brusque d'une veine supersonique," Revue Générale des Sciences Appliquées, 114:229-237 (1955).

136. Stett, L. E., and Valerino, A. S., "Effect of Freestream Mach Number on Gross-Force and Pumping Characteristics of Several Ejectors," NACA RM E54K23a (1955).

137. Weinstein, A. S., Osterle, J. F., and Forstall, W., "Momentum Diffusion from Slot Jet into Moving Secondary," ASME Paper No. 55-A60 (1955).

138. Standards for Steam Jet Ejectors, 3rd Edition, New York, N.Y., Heat Exchange Institute, 80 pp. (1956).

139. Cheers, F., "Development of an Air Injector," National Research Council of Canada, Report No. MT. 31 (1956).

140. Falanga, R. A., and Leiss, A., "Free-Flight Investigation at Transonic Speeds of Drag Coefficients of a Boattail Body of Revolution with a Simulated Turbojet Exhaust Issuing at the Base from Conical Short-Length Ejectors," NACA RM L56H23 (1956).

141. Flores, J. R., McJones, R. W., and Sain, J. A., "Generalized Performance of Cylindrical and Conical Aircraft Ejectors," Aircraft Division, Douglas Aircraft Company, Inc., Long Beach, Cal. (1956).

142. Jaeckel, R., "Neuere Forschungsergebnisse der Vakuumtechnik," Chemie-Ingenieur-Technik, 28(3):201-202 (1956).

143. Linck, C. G., "Can Air-Operated Ejectors Solve Your Problem," Engineering, 60(6):69-71 (1956).

144. Schupp, F., "Neue Strahlsauger fuer Kondensationsanlagen," Brennstoff-Waerme-Kraft, 8(12):576-579 (1956).

145. Vogel, R., "Ein Beitrag zur Berechnung von Strahlapparaten," Technische Hochschule-Wissenschaft Zeitschrift, 6(6):1171-1177 (1956-1957).

146. Vogel, R., "Practical Application of Air Ejectors," NASA TT F-9352 (1956).

147. Berkley, F. D., "Ejectors Give Any Suction Pressure," Engineering, 64(4):255-260 (1957).

148. Blatchley, C. G., "Control of Steam-Jet Vacuum Pumps," ASME Paper No. 57-F-15 (1957).

149. Carriere, P., "Interaction de l'ecoulement externe et de l'ecoulement interne a la sortie d'un reacteur, aux vitesses trans-soniques, et supersoniques," Compte rendu des journées internationales de sciences aéronautiques (May 1957).

150. Hasel, L. E., and Sinclair, A. R., "A Preliminary Investigation for Improving the Pressure-Recovery Characteristics of Variable-Geometry Supersonic-Subsonic Diffuser Systems," NACA RM L57H02 (1957).

151. Kaye, J., and Rivas, M. A., "Experimental and Analytical Study of Two-Component Two-Phase Flow in Ejector with Condensation," ASME Paper No. 57-HT-35 (1957).

152. Pfleiderer, C., "Uberschallstroemungen von hoher Machzahl bei kleinen Stroemungsgeschwindigkeiten," VDI Zeitschrift, 99(30): 1535-1536 (1957).

153. Polikovskii, V. I., Perel'man, R. G., and Ivanov, Yu.A., "Ob odnoi vozmozhnosti umen'sheniya dliny ezhektora," Teploenergetika, 4(9):23-26 (1957).

154. Schupp, F., "Wirtschaftliche Entleuftung, Vorwaermung und Entgasgung im Kondensationsbetrieb," Brennstoff-Waerme-Kraft, 9(7):320-323 (1957).

155. Berman, L. D., and Zinger, N. M., "Sravnenie Raznykh Tipov Vozdushnykh Nasosov Olya Kondensatorov Turbin," Teploenergetika, 5(11):46-55 (1958).

156. Broecker, E., "Vermischung von Fluessigkeits- odor Gasstroemen bei Kleiner Gesamtdruckaenderung," Forschung auf dem Gebiete des Ingenieurwesens, 24(6):169-177 (1958); 25(1):17-25 (1959).

157. Crocco, L., "One-Dimensional Treatment of Steady Gas Dynamics," Fundamentals of Gas Dynamics," Emmons, H. W., Editor, Princeton, N.J., Princeton University Press, Vol. III, pp. 272-293 (1958).

158. Fabri, J., and Paulon, J., "Theory and Experiments on Supersonic Air-to-Air Ejectors," NACA TM 1410 (1958).

159. Fabri, J., and Siestrunck, R., "Supersonic Air Ejectors," Advances in Applied Mechanics, New York, N.Y., Academic Press, Vol. V, pp. 1-34 (1958).

160. Filimonov, A. G., "Gas Ejectors," Automobile Engineer, 48(7):271-274 (1958).

161. Hoge, H. J., Eichacker, S. S., and Fiske, D. L., "Studies of Jet Compression - I, Apparatus and Methods," ASME Paper No. 58-SA-13 (1958).

162. Linck, C. G., "Selecting Ejectors for High Vacuum," Chemical Engineering, 65(1):145-150 (1958).

163. Mitchell, J. W., "Design Parameters for Subsonic Air-Air Ejectors," Office of Naval Research, Technical Report No. 40 (1958).

164. Polikovskii, M. V., and Shklover, G. G., "Eksperimental'noe issledovanie parostruinykh ezhektorov," Teploenergetika, 5(9): 46-51 (1958).

165. Rethorst, S., and Royce, W., "The Annular Jet and Thrust Augmentation," Vehicle Research Corporation, Pasadena, Cal., N63-86009 (1958).

166. Runckel, J. F., "Preliminary Transonic Performance Results for Solid and Slotted Turbojet Nacelle Afterbodies Incorporating Fixed Divergent Jet Nozzles Designed for Supersonic Operation," NASA TM 10-24-58L (1958).

167. Swihart, J. M., and Mercer, C. E., "Investigation at Transonic Speeds of a Fixed Divergent Ejector Installed in a Single-Engine Fighter Model," NACA RM L57L10a (1958).

168. Barton, D. L., and Taylor, D., "An Investigation of Ejectors without Induced Flow," Arnold Engineering Development Center Report No. AEDC-TN-59-145 (1959).

169. Codegone, C., "Experienze su eiettori," Termotecnica, 13(10):481-495 (1959).

170. Douchez, M., "Les ejecteurs," Annales de l'Institut Technique du Baitment et des Travaux Publics, 12(144):1264-1277 (1959).

171. Fortini, A., "Performance Investigation of a Nonpumping Rocket-Ejector System for Altitude Simulation," NASA TN D-257 (1959).

172. Howell, R. R., "Experimental Operating Performance of Single-Stage Annular Air Ejector," NASA TN D-23 (1959).

173. Norton, H. T., Jr., Marlowe, D. C., and Mercer, C. E., "Transonic Off-Design Performance of a Fixed Divergent Ejector Designed for Mach Number of 2.0," NASA TM X-165 (1959).

174. Richards, W. G., and Osborne, W. C., "Very Low Pressure Air Ejector," Institution of Heating & Ventilating Engineers, 27:172-179 (1959).

175. Schupp, F., "Betriess- und Versuchsergebnisse von neuen Strahlsaugapparaten," Brennstoff-Waerme-Kraft, 11(9):420-424 (1959).

176. Schupp, F., "Regelbare Mehrfach-Strahlsauger," VDI Zeitschrift, 101(34):1630-1635 (1959).

177. Asquith, W., "Entlueften von Oberflaechenkondensatoren," Siemens Zeitschrift, 34(4):150-155 (1960).

178. Chisolm, R.G.A., "Design and Calibration of an Air Ejector to Operate Against Various Back Pressures," Toronto University Institute of Aerophysics, Report No. UTIA TN 39 (1960).

179. Corson, B. W., Jr., and Mercer, C. E., "Static Thrust of an Annular Nozzle with a Concave Central Base," NASA TN D-418 (1960).

180. Gertsma, L. W., and Yeager, R. A., "Preliminary Investigation of Off-Design Performance of Divergent-Ejector-Type Rocket Nozzles," NASA TM X-250 (1960).

181. Hicks, H. H., Jr., "The Theory of Ejectors," Ph.D. Thesis, Department of Chemical Engineering, University of Michigan, Ann Arbor (1960).

182. Jones, W. L., Price, H. S., and Lorenzo, C. F., "Experimental Study of Zero-Flow Ejectors using Gaseous Nitrogen," NASA TN D-203 (1960).

183. Kastner, L. J., and McGarfy, J. B., "Mass Flow and Mixing Process in Low-Velocity Air Ejectors," Engineer, 210(5453):190-192 (1960).

184. Lewis, W.G.E., and Drabble, J. S., "Ejector Experiments," National Gas Turbine Establishment, Report No. R 151 (1960).

185. Schem, O., "Luftabsaugung bei Dampfturbinen-Kondensatoren mit einer Kombination aus zwei Dampfstrahlern und einer Elmo-Pumpe," Siemens Zeitschrift, 34(11):753-758 (1960).

186. Yeager, R. A., "Investigation of an Ejector-Type Nozzle for Rocket Application," NASA TM X-251 (1960).

187. Bauer, R. C., and German, R. C., "Some Reynolds Number Effects on the Performance of Ejectors without Induced Flow," Arnold Engineering Development Center Report No. AEDC-TN-61-87 (1961).

188. Bauer, R. C., and German, R. C., "The Effect of Second-Throat Geometry on the Performance of Ejectors without Induced Flow," Arnold Engineering Development Center Report No. AEDC-TN-61-133 (1961).

189. German, R. C., and Bauer, R. C., "Effects of Diffuser Length on the Performance of Ejectors without Induced Flow," Arnold Engineering Development Center Report No. AEDC-TN-61-89 (1961).

190. Johnson, J. K., Jr., Shumpert, P. K., and Sutton, J. F., "Steady Flow Ejector Research Program," Final Report, Lockheed-Georgia Company, Marietta, Geo., N62-16458 (1961).

191. Mihaloew, J. R., "Internal-Performance Evaluation of Two Fixed-Divergent Shroud Ejectors," NASA TN D-763 (1961).

192. Mihaloew, J. R., and Stofan, A. J., "Internal-Performance of Two-Position Divergent Shroud Ejector," NASA TN D-762 (1961).

193. Taylor, D., Barton, D. L., and Simmons, M., "An Investigation of Cylindrical Ejectors Equipped with Truncated Conical Inlets," Arnold Engineering Development Center Report No. AEDC-TN-60-224 (1961).

194. Ueda, T., "On Performance Characteristics of Steam Ejectors," Bulletin of the Japanese Society of Mechanical Engineers, 4(13): 124-131 (1961).

195. Bonnington, S. T., "The Design of Ejectors Driven by and Entraining Compressible Fluids," British Hydromechanics Research Association, NASA Accession No. N65-80898 (1962).

196. Chow, W. L., and Korst, H. H., "Influence on Base Pressures by Heat and Mass Additions," ARS Journal, 32(7):1094-1095 (1962).

197. Daitch, A. M., Sparkes, H. A., and Westman, R. E., "Mathematical Model of a Diffuser-Ejector System for Rocket Engine Altitude Simulation - Final Report," Systems Engineering Division, Daniel, Mann, Johnson, and Mendenhall and Associates, Los Angeles, Cal., AD-869217 (1962).

198. Peters, C. E., and Wehofer, S., "Theoretical Performance of Air-Driven Ejectors for Pumping Rocket Exhaust Gases," Arnold Engineering Development Center Report No. AEDC-TDR-62-134 (1962).

199. Simonson, A. J., and Schmeer, J. W., "Static Thrust Augmentation of a Rocket-Ejector System with a Heated Supersonic Primary Jet," NASA TN D-1261 (1962).

200. Addy, A. L., "On the Steady State and Transient Operating Characteristics of Long Cylindrical Shroud Supersonic Ejectors (With Emphasis on the Viscous Interaction Between the Primary and Secondary Streams)," Ph.D. Thesis, Department of Mechanical Engineering, University of Illinois, Urbana (1963).

201. De Hann, R. E., "Supersonic Ejectors with Mixing at Constant Cross-Section, 1. Theoretical Part," Applied Scientific Research, 12A(3): 293-313 (1963-1964).

202. Eastman, R. H., "Effects of a Particle-Laden Driving Stream on Ejector Efficiency," Joseph Kaye Company, Inc., Report No. 52 (1963).

203. Engel, M. O., "Some Problems in Design and Operation of Jet Ejectors," Proceedings of the Institution of Mechanical Engineers, 177(13):347-362 (1963).

204. Francis, W. E., "A Generalized Procedure for Optimum Design of Injectors, Ejectors, and Jet Pumps," Midland Research Station, The Gas Council, 66-11912 (1963).

205. German, R. C., Panesci, J. H., and Clark, H. K., "Zero Secondary Flow Ejector-Diffuser Performance using Annular Nozzles," Arnold Engineering Development Center Report No. AEDC-TDR-62-196 (1963).

206. Hale, J. W., "Auxiliary Ejector Effects on Rocket-Driven Diffuser Performance during Thrust Variation," Arnold Engineering Development Center Report No. N63-22022 (1963).

207. Hale, J. W., "Comparison of Diffuser-Ejector Performance with Five Different Driving Fluids," Arnold Engineering Development Center Report No. AEDC-TDR-63-207 (1963).

208. Hale, J. W., "Investigation of Two-Nozzle Cluster Diffuser-Ejector with and without Ejected Mass," Arnold Engineering Development Center Report No. AEDC-TDR-63-130 (1963).

209. Moore, G. F., "Successful Operation of Steam Vacuum Jets," ASME Paper No. 63-WA-161 (1963).

210. Panesci, J. H., and German, R. C., "An Analysis of Second-Throat Diffuser Performance for Zero-Secondary-Flow Ejector Systems," Arnold Engineering Development Center Report No. AEDC-TDR-63-249 (1963).

211. Poppe, D. G., "Dangerous Air Fan Removed - Replaced by Venturi System," Plant Engineering, 17(7):152-153 (1963).

212. Power, R. B., "Steam-Jet Air Ejectors - Specification, Evaluation, and Operation," ASME Paper No. 63-WA-143 (1963).

213. Sirieix, M., "Contribution a l'etude des ejecteurs supersoniques," Association Technique Maritime et Aeronautique, T.P. 32 (1963).

214. Traksel, J., "Simplified Ejector and Jet Thrust Augmentor Theory," Lockheed Aircraft Corporation (1963).

215. Uryukov, B. A., "Teoriya differentsial'nog ezhektora," Zhurnal Priklandnoi Mekhaniki i Tekhnicheskoi Fiziki, 5:41-47 (1963).

216. Bauer, R. C., "Theoretical Base Pressure Analysis of Axisymmetric Ejectors without Induced Flow," Arnold Engineering Development Center Report No. AEDC-TDR-64-3 (1964).

217. Beheim, M. A., "Ejectors and Thrust Augmentation," NASA, Proceedings of Conference on Large Liquid Rocket Systems, Lewis Research Center, Cleveland, Ohio, 1964, pp. 315-323.

218. Chow, W. L., and Addy, A. L., "Interaction between Primary and Secondary Streams of Supersonic Ejector Systems and their Performance Characteristics," AIAA Journal, 2(4):686-695 (1964).

219. De Hann, R. E., "Supersonic Ejectors with Mixing at Constant Cross-Section, 2. Experimental Part," Applied Scientific Research, 14A(1,2):57-76 (1964-1965).

220. Dyke, M. C., and Seddon, J., Ejectors and Mixing of Streams, AGARD Bibliography 6, 1954, 585 References.

221. Elliott, G. A., "An Experimental Study of Static Thrust Augmentation Using a Rocket-Ejector System," M.S. Thesis, School of Engineering, Southern Methodist University, Dallas, Texas (1964).

222. Fitch, R. E., "Analysis of the Inviscid Interaction Between an Underexpanded Rocket Exhaust and a Confined Secondary Stream," Boeing, Report No. D2-36211-1 (1964).

223. Geiger, F. W., "A One-Dimensional Thrust Augmentation Calculation," Research Laboratories, Brown Engineering Company, Inc., Huntsville, Alabama, Report No. X65-18078 (1964).

224. Hale, J. W., "Influence of Pertinent Parameters on Ejector-Diffuser Performance with and without Ejected Mass," Arnold Engineering Development Center Report No. AEDC-TDR-64-134 (1964).

225. Harper, D. J., "The Thrust Augmentation of Rocket Motors at High Altitudes," Journal of the Royal Aeronautical Society, 68(648): 799-807 (1964).

226. Harris, L. S., "Air Cooled Condensers for Steam Jet Vacuum Pumps," ASME Symposium on Air-Cooled Heat Exchangers, August 1964, pp. 142-151.

227. Lynch, O. R., and Carman, C. T., "An Investigation of the Performance of a Hot-Gas Pump with and without Induced Flow," Arnold Engineering Development Center Report No. AEDC-TDR-64-234 (1964).

228. Polak, P., "Notes on Jet Thrust Augmentation," Engineer, 217(5640): 383-385 (1964).

229. Power, R. B., "Steam-Jet Air Ejectors," Hydrocarbon Processing and Petroleum Refiner, 43(2,3,4):121-126, 138-142, 149-152 (1964).

230. Scott, W. J., "Experimental Thrust Augmentation of a Variable Geometry, Two-Dimensional Coanada Wall Jet Ejector," National Research Council of Canada, Aeronautical Report No. LR-394 (1964).

231. Wan, Chia-An, "A Study of Jet Ejector Phenomena," Aerophysics Department, Mississippi State University, NASA Accession No. N65-26099 (1964).

232. Chow, W. L., and Yeh, P. S., "Characteristics of Supersonic Ejector Systems with Non-Constant Area Shroud," AIAA Journal, 3(3):525-527 (1965).

233. Delery, J., "Recollement d'un jet supersonique de revolution sur une paroi cylindrique coaxiale," La Recherche Aerospatiale, No. 104 (1965).

234. Fellous, J. R., "Calcul d'ejecteur - pumpe a chambre de mélande cylindrique," Houille Blanche, 20(2):137-142 (1965).

235. German, R. C., and Panesci, J. H., "Improved Methods for Determining Second-Throat Diffuser Performance of Zero-Secondary-Flow Ejector Systems," Arnold Engineering Development Center Report No. AEDC-TDR-65-124 (1965).

236. Hardy, J. M., and Delery, J., "Possibilities actuelles d'etude theorique d'une tuyere supersonique a double flux," Office Nationale d'Etudes et de Recherches Aeronautiques, Chatillon-sous-Bagneux, Seine, France, Technical Paper No. 287 (1965).

237. Hoge, H. J., and Segars, R. A., "Choked Flow: A Generalization of the Concept and Some Experimental Data," AIAA Journal, 3(12):2177-2183 (1965); 4(7):1309-1310 (1966).

238. Lee, C. G., and Inman, S. J., "Analysis of Flow from Plug Nozzles with Secondary Ejector Systems," NASA TN R-128 (1965).

239. Middleton, D., "The Noise of Ejectors," Aeronautical Research Council, Great Britain, Report No. ARC-R/M-3389 (1965).

240. Nelson, J. R., "Investigation of the Mixing Region Between the Primary and Secondary Streams of a Two-Dimensional Supersonic Air-Air Ejector System," M.S. Thesis, School of Engineering, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio (1965).

241. Robozhev, A. V., "Primenenie nomogramm dlya rascheta mnogostupenchatykh ezhektorov," Energomashinostroenie, 8:21-26 (1965).

242. Scott, J. E., Jr., "Mixing and Combustion of a Supersonic Fuel Jet and a Subsonic, Coaxial Gas Stream," AIAA, 2nd Annual Meeting, San Francisco, Cal., July 26-29, 1965.

243. Sillem, H., "Untersuchungen zur kompressiblen Gasstroemung in Strahlapparaten mit konstantem Mischrohrquerschnitt," VDI Zeitschrift, 107(12):535 (1965).

244. Strand, G. E., "A Study of a Supersonic Ejector Mixing Chamber," M.S. Thesis, School of Engineering, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio (1965).

245. Uebelhack, H. T., "Supersonic Air-Air Ejectors with Second Throat Diffusers," von Kármán Institute for Fluid Dynamics, Report No. VKI-TN-28 (1965).

246. Vasil'ev, Yu.N., "Great-Pressure-Drop Gas Ejector with Additional Nozzle," (Translated from: Russian Patent 134804, Appl. 664925/25, April 28, 1960), Foreign Technology Division, Wright-Patterson Air Force Base, Ohio, Report No. FTD-TT-64-1198 (1965).

247. Vogel, R., "Theoretical and Experimental Investigation of Air Ejectors," (Translated from: "Theoretische und experimentelle Untersuchungen an Strahlapparaten," Maschinenbautechnik, 5(12): 619-637, 1956), NASA TT F-9353 (1965).

248. Witte, J. H., "Efficiency and Design of Liquid-Gas Ejectors," British Chemical Engineering, 10(9):602-607 (1965).

249. Barth, E., "Effects of Nozzle Geometry on Jet Flow Ejectors," Ph.D. Thesis, Technische Hochschule, Hanover, West Germany (1966).

250. Brown, P., "Seventeen-Inch TWT Tests of a Coannular Ejector with a Clamshell Reverser," Research Laboratories, United Aircraft Corporation, East Hartford, Conn., AD-821265L (1966).

251. Fabri, J., Le Grives, E., and Mechard, J., "Sur le melange a section constante de deux flux a enthalpies differentes," France (1966).

252. German, R. C., Bauer, R. C., and Panesci, J. H., "Methods for Determining the Performance of Ejector-Diffuser Systems," Journal of Spacecraft, 3(2):193-200 (1966).

253. Heiser, W. H., "Thrust Augmentation," ASME, Gas Turbines and Products Show, Zurich, Switzerland, March 13-17, 1966.

254. Hoge, H. J., and Segars, R. A., "An Equation for the Entrainment of Ejectors," AIAA Journal, 4(9):1689-1691 (1966).

255. Korst, H. H., Addy, A. L., and Chow, W. L., "Installed Performance of Air-Augmented Nozzles Based on Analytical Determination of Internal Ejector Characteristics," Journal of Aircraft, 3(6): 498-506 (1966).

256. Krenkel, A. R., and Kipowsky, H. H., "Design Analysis of Central and Annular-Jet Ejectors," Aerospace Research Labs, Wright-Patterson Air Force Base, Ohio, Project No. 7065 (1966).

257. Loth, J. L., "Theoretical Optimization of Staged Ejector Systems," Arnold Engineering Development Center Report No. AEDC-TR-66-2 (1966).

258. Okeefe, P. C., "Seventeen-Inch TWT Tests on a Coannular Ejector with a Clamshell Reverser," Research Laboratories, United Aircraft Corporation, East Hartford, Conn., AD-821266L (1966).

259. Schroeder, H. J., "Der Pulsozerstaeuber ein selbstansaugendes Strahlgeblaese mit hoher Foerderlsitung," Forschung im Ingenieur-Wesen, 32(3):91-95 (1966).

260. Stewart, D., "Subsonic Wind Tunnel Tests of a Clamshell-Shroud Ejector Nozzle for the Supersonic Transport Engine," Research Laboratories, United Aircraft Corporation, East Hartford, Conn. AD-821268L (1966).

261. Verbridge, D., "Experimental Performance Evaluation of a Clamshell Shroud Ejector Nozzle for the Supersonic Transport Engine," Research Laboratories, United Aircraft Corporation, East Hartford, Conn., AD-821269L (1966).

262. Verbridge, D., "Experimental Performance Evaluation of a Proposed Translating Shroud Ejector Nozzle for the Supersonic Transport Engine," Research Laboratories, United Aircraft Corporation, East Hartford, Conn., AD-821267L (1966).

263. Yarborough, P. P., "Investigation of the Performance of an Ejector-Afterburner for Thrust Augmentation of a Small Rocket Engine," School of Engineering, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio (1966).

264. Adamas, D. M., "Performance Analysis of Hypersonic Air-Augmented Supersonic Combustion Propulsion Vehicles," AIAA Paper No. 67-226 (1967).

265. Baykov, U. S., and Vasilev, Yu., "Vane Machines in Jet Apparatuses (Selected Articles)," (Translated from: Lopatochnye Mashiny i Struynye Apparaty, USSR, 1:235-238, 1966), Foreign Technology Division, Wright-Patterson Air Force Base, Ohio, Report No. FTD-MT-24-185-67 (1967).

266. Bernstein, A., Heiser, W. H., and Hevenor, C., "Compound-Compressible Nozzle Flow," Journal of Applied Mechanics, 34(3): 548-554 (1967).

267. Campbell, W. S., and von Ohain, H., "Thrust Augmentation for V/STOL: ARL's Research and Concepts," Aerospace Research Labs, Wright-Patterson Air Force Base, Ohio, Report No. ARL-67-0065 (1967).

268. Hardy, J. M., and La Combe, H., "Supersonic Bypass Nozzles: Computing Methods," Revue Francaise de Méchanique, 24:49-59 (1967).

269. Harris, G. L., "The Self-Preserving Turbulent Jet Ejector," AIAA Paper No. 67-127 (1967).

270. Huang, K. P., and Kisielowski, E., "An Investigation of the Thrust Augmentation Characteristics of Jet Ejectors," Dynasciences Corporation, AD 651-946 (1967).

271. Johnson, W. S., "Analytical and Experimental Study of the Pulsejet Ejector," Ph.D. Thesis, Clemson College, South Carolina (1967).

272. Kogan, P. A., "Razrabotka i issledovanie novykh malogabaritnykh shchelevykh gazostruinykh ezhektorov," Energetika, 4:64-70 (1967).

273. Mains, W. D., and Richenberg, R. E., "Steam Jet Ejectors in Pilot and Production Plants," Chemical Engineering Progress, 63(3):84-88 (1967).

274. Newman, E. F., "How to Specify Steam-Jet Ejectors," Chemical Engineering, 74(8):203-208 (1967).

275. Wade, B. S., "Parametric and Experimental Analysis of Ejector Performance," M.S. Thesis, Naval Postgraduate School, Monterey, Cal. (1967).

276. Ahren, B., "Analysis of Ejectors used as Supersonic Propelling Nozzles for Jet Engines," Ph.D. Thesis, Kungliga Tekniska Högskolan, Stockholm, Sweden (1968).

277. Arkadov, Iu.K., "A Gas Ejector with a Nozzle Perforated by Longitudinal Slots," Akademiia Nauk SSSR, Izvestiia, Mekhanika Zhidkosti i Gaza, 71-74 (1968).

278. Bradshaw, P., Flintoff, J. L., and Middleton, D., "Unexplained Scale Effects in Ejector Shroud 'Howling'," Journal of Sound and Vibration, 7(2):183-190 (1968).

279. Chenoweth, F. C., and Steffen, F. W., "Comparison of Experimental and Predicted Heat Transfer Characteristics for a Cylindrical Ejector," NASA TM X-1641 (1968).

280. Fourtanier, J. M., and Oiknine, C., "Study of Cylindrical Ejectors with Zero Induced Flow," Doc-Air-Espace, pp. 41-56 (1968).

281. Gobbell, W. C., and Hale, J. W., "Determination of Annular Ejector-Diffuser Performance Improvement," Arnold Engineering Development Center Report No. AEDC-TR-68-68 (1968).

282. Grodzovskii, G. L., "Contribution to the Theory of a High-Compression Gas Ejector with a Cylindrical Mixing Chamber," Akademiia Nauk SSSR, Izvestiia, Mekhanika Zhidkosti i Gaza, 3:35-44 (1968).

283. Hanbury, W. T., "The Performance of an Air-to-Air Ejector According to a Quasi-One-Dimensional Theory," Aeronautical Research Council, Great Britain, Report No. ARC-29341 (1968).

284. Imfeld, W. F., "Analysis of F-111 Blow-In Door Ejector Nozzle - Final Report, Aug. 1967 - Feb. 1968," Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, Report No. ASD-TR-68-20 (1968).

285. Johnson, W. S., and Yang, T., "A Mathematical Model for the Prediction of the Induced Flow in a Pulsejet Ejector with Experimental Verification," ASME Paper No. 68-WA/FE-33 (1968).

286. Johnston, S. C., "Experimental Investigation of a Supersonic Air-Air Ejector Operating with a Second Throat," von Kármán Institute for Fluid Dynamics, Report No. VKI-TN-45 (1968).

287. Loth, J. L., "Theoretical Optimization of Staged Ejector Systems," Arnold Engineering Development Center Report No. AEDC-TR-68-80 (1968).

288. Peters, C. E., "Turbulent Mixing and Burning of Coaxial Steams inside a Duct of Arbitrary Shape," Ph.D. Thesis, University of Brussels, Belgium (1968).

289. Taylor, D., and Toline, F. R., "Summary of Exhaust Gas Ejector-Diffuser Research," Arnold Engineering Development Center Report No. AEDC-TR-68-84 (1968).

290. Vasilyev, Yu.N., "Theory of a Supersonic Gas Ejector with a Cylindrical Mixing Chamber," (Translated from: Bladed Machines and Jet Devices, Issue 2, Vasil'ev, Iu.N., Editor, Moscow, Izdatel'stvo Mashinostroenie, pp. 171-235, 1967), NASA TT-F-11554 (1968).

291. "Ejector System Performance Analysis in Hot Gas Exhaust Duct," FORTRAN IV Program, Aerojet-General Corporation, El Monte, Cal. (1969).

292. Anderson, R. E., and Graham, B., "Improvement of Ejector-Diffuser Performance by Reduction of Backflow," Journal of Aircraft, 6(1): 73-74 (1969).

293. Di Tommaso, S., "General Semiempirical Method for Determining the Performance Curves of Supersonic Air-to-Air Ejectors," Tecnica Italiana, 34(4):125-131 (1969).

294. Dunin, N. A., and Zhadin, G. P., "Determination of the Actual Shot Delivery from an Ejector Nozzle During Shot Peening," Kazanskii Aviatsionnyi Institut, Trudy, Seriia Aviatsionnaia Tekhnologiia i Organizatsiia, Proizvodstva, 112:46-52 (1969).

295. Kalmykov, I. I., and Mosin, I. I., "Calculation of the Maximum Compression Ratio of an Ejector," Kazanskii Aviatsionnyi Institut, Trudy, Seriia Aviatsionnye Dvigateli, 110:27-34 (1969).

296. Miller, J. R., "The Liquid-Gas Ejector," Ph.D. Thesis, New Mexico State University, University Park (1969).

297. Nagamatsu, H. T., Pettit, W. T., and Sheer, R. E., Jr., "Flow and Acoustic Measurements on a Convergent Nozzle Supersonic Jet Ejector," Mechanical Engineering Laboratory, General Electric Company, Schenectady, N. Y. (1969).

298. Nazarova, L. I., and Sedelnikov, T.Kh., "The Dispersion Equation of a 2-Dimensional Ejector," Physics of Aerodynamic Noise, Rimskii-Korsakov, A. V., Editor, (Translated from: Fizika Aerodinamicheskikh Shumov, Moscow, Izdatel'stvo Nauka, 1967), National Lending Library for Science and Technology, Boston Spa, Yorks, England, pp. 130-137 (1969).

299. Oiknine, C., Robert, C., and Sananes, F., "Study of Supersonic Ejectors," Association Francaise des Ingénieurs et Techniciens de l'Aéronautique et de l'Espace, 6th Colloque d'Aérodynamique Appliquée, Toulouse, France, November 12-14, 1969.

300. Samanich, N. E., and Huntley, S. C., "Thrust and Pumping Characteristics of Cylindrical Ejectors using Afterburning Turbojet Gas Generator," NASA TM X-52565 (1969).

301. Armstrong, F. W., and Lewis, W.G.E., "Some Experiments on Two-Stream Propelling Nozzles for Supersonic Aircraft," International Council of the Aeronautical Sciences, 7th Congress, Rome, Italy, September 14-18, 1970.

302. Bowman, J. E., and Clayden, W., "Base Pressure on a Boat-Tailed Afterbody at Free Stream Mach Number 2 with Gas Ejection from Porous and Multi-Nozzle Bases," Royal Armament Research and Development Establishment, Forst Halstead, Great Britain, Report No. RARDE-MEMO-20/70 (1970).

303. Dobrovolskii, G. P., "Equation of Conservation of Momentum and the Characteristic of an Ejector," Teplofizika i Teplotekhnika, 18:133-139 (1970).

304. Fancher, R. B., "A Compact Thrust Augmenting Ejector Experiment," Aerospace Research Labs, Wright-Patterson Air Force Base, Ohio, Report No. ARL-70-0137 (1970).

305. Johns, A. L., and Steffen, F. W., "Performance of an Auxiliary Inlet Ejector Nozzle with Fixed Doors and Single-Hinge Trailing-Edge Flap," NASA TM X-2027 (1970).

306. Kalmykov, I. I., and Mosin, I. I., "Influence of Nozzle Structure Design on the Operation of an Ejector Stage with a Conical Mixing Chamber," Kazanskii Aviatsionnyi Institut, Trudy, Seriia Aviatsionnye Dvigateli, 114:48-57 (1970).

307. Kukanov, F. A., and Mezhirov, I. I., "Operation of a Gas Ejector in the Case of Differing Physical Parameters of the Mixing Gases," Tsagi, Uchenye Zapiski, 1(4):103-108 (1970).

308. Middleton, D., "Theoretical and Experimental Investigations into the Acoustic Output from Ejector Flows," Journal of Sound and Vibration, 11(4):447-473 (1970).

309. Quinn, B., "The Characteristics of a Small Variable Geometry Ejector - Final Report," Aerospace Research Labs, Wright-Patterson Air Force Base, Ohio, Report No. ARL-70-0071 (1970).

310. Wright, W. A., and Shahrokhi, F., "Investigation of High Mass Ratio, Multiple-Nozzle, Air-Ejector Systems," Journal of Spacecraft and Rockets, 7(12):1489-1491 (1970).

311. Alperin, M., and Marlotte, G. L., "A Jet Flap Diffuser Ejector," Flight Dynamics Research Corporation, Burbank, Cal., Report No. TR-71-06-01 (1971).

312. Barna, P. S., "Performance and Noise Generation Studies of Supersonic Air Ejectors," Proceedings of the 7th International Congress on Acoustics, Budapest, Hungary, August 18-26, 1971, Vol. 2, pp. 481-484; NASA CR-2056 (1972).

313. Carey, J. H., Gilbert, G. B., and Hickman, K. E., "High Entrainment Ejector Design," ASME Paper No. 71-FE-34 (1971).

314. Dobrovolskii, G. P., "Approximate Method of Calculation of Gas Ejectors," Teplofizika i Teplotekhnika, 20:125-129 (1971).

315. Fancher, R. B., "Low Area Ratio Thrust Augmenting Ejectors," AIAA Paper No. 71-576 (1971).

316. Forman, I., "Ejector Simulation," (Translated from: Vyzkumny a Zkusebni Letecky Ustav, Letnany, Zprayodaj Vzlu, Czechoslovakia, 5(50):33-38, 1966), Foreign Technology Division, Wright-Patterson Air Force Base, Ohio, Report No. FTD-HT-23-811-70 (1971).

317. Gladkov, E. P., and Vasilev, Iu.N., "Experimental Study of a Vacuum Water-Air Ejector with a Multibarreled Nozzle," Lopatochnye Mashiny i Struinye Apparaty, 5:262-306 (1971).

318. Hardy, J. M., "Influence of Certain Characteristic Parameters on Ejector Performance," Inlets and Nozzles for Aerospace Engines, AGARD CP-91-71, 12 pp. (1971).

319. Kalmykov, I. I., and Mosin, I. I., "Effect of Certain Geometrical Parameters on the Operation of an Ejector with a Conical Mixing Chamber," Aviatsionnaia Tekhnika, 14(1):104-112 (1971).

320. Paulon, J., "Theoretical and Experimental Study of the Coexistence of Two Flows in a Constant-Section Duct," Inlets and Nozzles for Aerospace Engines, AGARD CP-91-71, 12 pp. (1971); ONERA TP-976 (1971).

321. Stern, R. D., "A Description of a Multichannel Ejector Test Facility and Preliminary Test Results," Aerospace Research Labs, Wright-Patterson Air Force Base, Ohio, Report No. ARL-71-0036 (1971).

322. Vasilev, Iu.N., "Theory of a Two-Phase Gas-Liquid Ejector with a Cylindrical Mixing Chamber," Lopatochnye Mashiny i Struinye Apparaty, 5:175-261 (1971).

323. Yule, A. J., "Two-Dimensional Self-Preserving Turbulent Mixing Layers at Different Free Stream Velocity Ratios," Aeronautical Research Council, Great Britain, Report No. ARC-R/M-3683 (1971).

324. Jet Pumps and Ejectors, British Hydromechanics Research Association, Proceedings of the Symposium, London, England, November 1, 1972, 12 Papers.

325. Addy, A. L., "The Analysis of Supersonic Ejector Systems," Supersonic Ejectors, AGARDograph No. 163, pp. 31-101 (1972).

326. Anderson, B. H., "Factors which Influence the Analysis and Design of Ejector Nozzles," AIAA Paper No. 72-46 (1972).

327. Ginoux, J. J., Editor, Supersonic Ejectors, AGARDograph No. 163, 1972, 5 Papers.

328. Gusev, V. N., "The Theory of the Critical Conditions of a Gas Ejector at Large Pressure Drops," (Translated from: Tsentralnyi Aerohidrodinamicheskii Institut, Uchenye Zapiski, USSR, 1(3): 91-96, 1970), Foreign Technology Division, Wright-Patterson Air Force Base, Ohio, Report No. FTD-MT-24-0005-72 (1972).

329. Hardy, J. M., "Theoretical Study of a By-Pass Convergent-Divergent Nozzle," L'Aeronautique et l'Astronautique, 37:23-36 (1972).

330. Hickman, K. D., Hill, P. G., and Gilbert, G. B., "Analysis and Testing of Compressible Flow Ejectors with Variable Area Mixing Tubes," Journal of Basic Engineering, 94(2):407-416 (1972).

331. Howlett, L. D., and Chow, W. L., "A Study of Nozzle and Ejector Flow Problems by the Method of Integral Relations," NASA CR-128066 (1972).

332. Kentfield, J.A.C., and Barnes, R. W., "The Prediction of the Optimum Performance of Ejectors," Proceedings of the Institution of Mechanical Engineers, 186(54):671-681 (1972).

333. Lapin, Iu.D., "Design of a Low-Pressure Gas Ejector," Izdatel'stvo Mashinostroenie, 4:115-120 (1972).

334. Lapin, Iu.D., "Investigation of the Operation of Low-Pressure Gas Ejectors," Izdatel'stvo Mashinostroenie, 5:90-94 (1972).

335. Mueller, T. J., and Sule, W. P., "Basic Flow Chracteristics of a Linear Aerospike Nozzle Segment," ASME Paper No. 72-WA/AERO-2 (1972).

336. Oddving, B., "Jet Pumps for Compressible Fluids at Supersonic Velocities," Proceedings of the 4th Conference on Fluid Machinery, Budapest, Hungary, September 11-16, 1972, pp. 915-929.

337. Peters, C. E., "Analysis of Ducted Mixing and Burning of Coaxial Streams," Supersonic Ejectors, AGARDograph No. 163, pp. 165-187 (1972).

338. Quinn, B., "A Simple Estimate of the Effect of Ejector Length on Thrust Augmentation," Aerospace Research Labs, Wright-Patterson Air Force Base, Ohio, Report No. ARL-73-0212 (1972); Journal of Aircraft, 10(5):313-314 (1973).

339. Solignac, J. L., and Delery. J., "Contribution to Aerodynamic Studies of Two-Stream Propulsion Systems," Israel Journal of Technology, 10(1-2) (1972); ONERA TP-1050 (1972).

340. Taylor, D., "Ejector Design for a Variety of Applications," Supersonic Ejectors, AGARDograph No. 163, pp. 103-163 (1972).

341. Uebelhack, H. T., "Analysis and Design Method for Ejector Systems with Second Throat Diffusers," Supersonic Ejectors, AGARDograph No. 163, pp. 17-30 (1972).

342. Uebelhack, H. T., "One Dimensional Inviscid Analysis of Supersonic Ejectors," Supersonic Ejectors, AGARDograph No. 163, pp. 1-16 (1972).

343. Vaughan, J. C., III, "Performance of Jet Ejectors," Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, Report No. ASD/XR-72-5 (1972).

344. Watanabe, I., "Experimental Investigations Concerning Pneumatic Ejectors, With Special Reference to the Effect of Dimensional Parameters on Performance Characteristics," Jet Pumps and Ejectors, British Hydromechanics Research Association, Proceedings of the Symposium, London, England, November 1, 1972, pp. 97-120.

345. Arkadov, Iu.K., "Investigation of a Gas Ejector Employing a Helical Nozzle," Aerodynamics of Channels and Jet Flows, Moscow, Izdatel'stvo Mashinostroenie, pp. 8?-91 (1973).

346. Baker, L. R., Jr., and McDermit, J. H., "Survey of Pressure Recovery Methods for Chemical Laser Application," Vol. VI, Chemical Laser Analysis Development, Huntsville Research and Engineering Center, Lockheed Missiles and Space Company, Inc., Huntsville, Ala., Report No. LMSC-HREC-TR-D306900-6 (1973).

347. Binder, G., and Favre-Marinet, M., "Mixing Improvement in Pulsating Turbulent Jets," Fluid Mechanics of Mixing, ASME, Proceedings of the Joint Meeting, Atlanta, Ga., June 20-22, 1973, pp. 167-172.

348. Brychta, O., "The 'Small Ejector' System," British Hydromechanics Research Association, Proceedings of the 5th Cranfield Fluidics Conference, Uppsala, Sweden, June 13-16, 1973, Vol. 1, pp. E7-97 to E7-112.

349. Cheng, D. Y., Wang, P., and Chisel, D. M., "Experimental Study on Optimization Parameters of a Supersonic Jet Ejector Thrust Augmentor," Journal of Aircraft, 10(9):569-570 (1973).

350. Fabris, G., and Fejer, A. A., "Confined Mixing of Multiple Jets," Fluid Mechanics of Mixing, ASME, Proceedings of the Joint Meeting, Atlanta, Ga., June 20-22, 1973, pp. 147-157.

351. Fishbach, L. H., "Performance of Ejector Wing Aircraft for Navy VTOL Fighters," NASA TM X-68237 (1973).

352. Gilbert, G. B., and Hill, P. G., "Analysis and Testing of Two-Dimensional Slot Nozzle Ejectors with Variable Area Mixing Sections," NASA CR-2251 (1973).

353. Hasinger, S. H., "Simplified Lay-Out of Supersonic, Heterogeneous Ejectors," Aerospace Research Labs, Wright-Patterson Air Force Base, Ohio, Report No. ARL-73-0149 (1973).

354. Kunstadt, E., "Study of Reverse-Flow Characteristics of a Tip Fan and an Ejector," M.S. Thesis, School of Engineering, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio (1973).

355. Marshek, K. M., and Otis, D. R., "Flow Limitations in a Supersonic Ejector," Fluid Mechanics of Mixing, ASME, Proceedings of the Joint Meeting, Atlanta, Ga., June 20-22, 1973, pp. 59-61.

356. Nagaraja, K. S., Hammond, D. L., and Graetch, J. E., "One-Dimensional Analysis of Compressible Ejector Flows Applicable to V/STOL Aircraft Design," AIAA Paper No. 73-1184 (1973).

357. Taylor, D., Duesterhaus, D. A., and Simmons, M., "Diffuser Studies," Arnold Engineering Development Center Report No. AEDC-TR-73-198 (1973).

358. Throndson, L. W., "Compound Ejector Thrust Augmentor Development," ASME Paper No. 73-GT-67 (1973).

359. Tirumalesa, D., "Theoretical Analysis of the Noise Characteristics of an Ejector Jet," Journal of Sound and Vibration, 30(4):465-481 (1973).

360. Zannetti, L., "One-Dimensional Study of Ejectors with a Supersonic Primary Flow and a Subsonic Secondary Flow," L'Aerotecnica - Missili e Spazio, 52(5):357-368 (1973).

361. Addy, A. L., and Mikkelsen, C. D., "An Investigation of Gas-Dynamic Flow Problems in Chemical Laser Systems," Department of Mechanical and Industrial Engineering, University of Illinois at Urbana-Champaign, Report No. UILU-ENG-74-4009 (1974).

362. Bevilaqua, P. M., and Toms, H. L., Jr., "A Comparison Test of the Hypermixing Nozzle," Aerospace Research Labs, Wright-Patterson Air Force Base, Ohio, Report No. ARL-74-0006 (1974).

363. Hedges, K. R., and Hill, P. G., "Compressible Flow Ejectors, Part I - Development of a Finite-Difference Flow Model," ASME Paper No. 74-FE-1 (1974).

364. Hedges, K. R., and Hill, P. G., "Compressible Flow Ejectors, Part II - Flow Field Measurements and Analysis," ASME Paper No. 74-FE-2 (1974).

365. Puzyrev, V. M., and Tagirov, R. K., "Calculation of Ejector Nozzle Flows," Akademiia Nauk SSSR, Izvestiia, Mekhanika Zhidkosti i Gaza, 1:111-118 (1974).

366. Vereshchaka, L. P., Kraiko, A. N., and Sternin, L. E., "Grid-Characteristic Method of Calculating Plane and Axisymmetrical Supersonic Two-Phase Flows," (Translated from: Lopatochnye Mashiny i Struynye Apparaty, USSR, 6:163-178, 1974), Foreign Technology Division, Wright-Patterson Air Force Base, Ohio, Report No. FTD-HT-23-676-74 (1974).

367. Addy, A. L., "The Analysis of Supersonic Ejector Systems," Ejectors, von Karman Institute, Lecture Series 79 (1975).

368 Delery, J., "Methods d'étude des éjecteurs supersonique Application aus tuyéres double-flux," Ejectors, von Karman Institute, Lecture Series 79 (1975).

369. Olivari, D., "Jets and Mixing Phenomena," Ejectors, von Karman Institute, Lecture Series 79 (1975).

370. Schmitt, H., "Summary of Possible Applications and Present Status of Various Ejector Techniques," Ejectors, von Karman Institute, Lecture Series 79 (1975).

371. Viets, H., "Thrust Augmenting Ejectors," Ejectors, von Karman Institute, Lecture Series 79 (1975).

372. Walker, B. J., "Chemical Laser Pumping Systems," Ejectors, von Karman Institute, Lecture Series 79 (1975).

7.2 CONSTANT-AREA SUPERSONIC-SUPERSONIC EJECTOR COMPUTER PROGRAM

7.2.1 Computer Program (CASSE)

```
C     ************************************************************   CASSE
C     *                                                          *   CASSE
C     *   CONSTANT-AREA SUPERSONIC-SUPERSONIC EJECTOR (CASSE)    *   CASSE
C     *                                                          *   CASSE
C     *                     C.D. MIKKELSEN                       *   CASSE
C     *                      9 MARCH 75                          *   CASSE
C     *                                                          *   CASSE
C     *             MECHANICAL ENGINEERING DEPARTMENT            *   CASSE
C     *      UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN          *   CASSE
C     *               URBANA, ILLINOIS 61801                     *   CASSE
C     *                                                          *   CASSE
C     *  CASSE IS A PROGRAM FOR CALCULATING THE PLANE OF         *   CASSE
C     *  OPERATION OF A CONSTANT-AREA SUPERSONIC-SUPERSONIC      *   CASSE
C     *  EJECTOR BY ONE-DIMENSIONAL ANALYSIS.  CASSE IS A        *   CASSE
C     *  FORTRAN IV PROGRAM WRITTEN FOR DEC SYSTEM-10 (F40).     *   CASSE
C     *                                                          *   CASSE
C     ************************************************************   CASSE
C                                                                    CASSE
C     ************************************************************   CASSE
C     *                                                          *   CASSE
C     *                    NOTATION SCHEME                       *   CASSE
C     *                                                          *   CASSE
C     *  VARIABLES ARE DEFINED AS FOLLOWS:                       *   CASSE
C     *                                                          *   CASSE
C     *  A : AREA                                                *   CASSE
C     *  G : (GAMMA) SPECFIC HEAT RATIO                          *   CASSE
C     *  M : MACH NUMBER                                         *   CASSE
C     *  MW: MOLECULAR WEIGHT RATIO                              *   CASSE
C     *  P : PRESSURE                                            *   CASSE
C     *  T : TEMPERATURE                                         *   CASSE
C     *  W : MASS FLOW RATE                                      *   CASSE
C     *                                                          *   CASSE
C     *  REPEATED LETTERS INDICATE RATIOS.                       *   CASSE
C     *  EXAMPLE: AS1AP1=AS1/AP1                                 *   CASSE
C     *                                                          *   CASSE
C     *  S: INDICATES SECONDARY OR DRIVEN STREAM PROPERTIES      *   CASSE
C     *  P: INDICATES PRIMARY OR DRIVING STREAM PROPERTIES       *   CASSE
C     *  M: INDICATES MIXED STREAM PROPERTIES                    *   CASSE
C     *  EXAMPLE: GM=MIXED STREAM SPECIFIC HEAT RATIO            *   CASSE
C     *                                                          *   CASSE
C     *  VARIABLES ARE DESIGNATED AS TO LOCATION AS FOLLOWS:     *   CASSE
C     *                                                          *   CASSE
C     *  1: MIXING TUBE ENTRANCE, THE CONFLUENCE POINT OF THE    *   CASSE
C     *     SECONDARY AND PRIMARY STREAMS                        *   CASSE
C     *  2: POINT IN THE MIXING TUBE AT WHICH THE SECONDARY      *   CASSE
C     *     STREAM IS RECOMPRESSED TO SONIC CONDITIONS           *   CASSE
C     *  3: MIXING TUBE EXIT                                     *   CASSE
C     *  EXAMPLE: PS1PP1=SECONDARY-TO-PRIMARY STATIC PRESSURE    *   CASSE
C     *           RATIO AT STATION 1                             *   CASSE
C     *                                                          *   CASSE
```

7.2.1 CASSE (Cont.)

```
C     *  0: INDICATES STAGNATION CONDITIONS                          *
C     *  EXAMPLE: TMOTPO=MIXED-TO-PRIMARY STAGNATION                 *
C     *           TEMPERATURE RATIO                                  *
C     *                                                              *
C     *  S: INDICATES "*" CONDITIONS                                 *
C     *  EXAMPLE: AP1APS=AP1/AP*                                     *
C     *                                                              *
C     *  VARIABLES NOT FOLLOWING THIS SCHEME ARE DEFINED AS          *
C     *  REQUIRED.                                                   *
C     *                                                              *
C     ****************************************************************
C
C
      IMPLICIT REAL*8(A-H,M,O-Z)
C
      DIMENSION MM3(21,3),PM3PPO(21,3),PM3PSO(21,3),PM3PS1(21,3)
C
      DIMENSION GM(21),MWMMWP(21),MWMMWS(21),PSOPPO(21),
     -PS1PPO(21),PS1PP1(21),PPOPSO(21),PPOPS1(21),PP1PS1(21),
     -TMOTPO(21),TMOTSO(21),WPWS(21),WSWP(21)
C
C
C     ****************************************************************
C     *                                                              *
C     *                     SPECIAL FUNCTIONS                        *
C     *                                                              *
C     ****************************************************************
C
C
      F(GX,MXX)=1.0+GX*MXX*MXX
      G(GX,MXX)=MXX*DSQRT(1.0+0.5*(GX-1.0)*MXX*MXX)
      H(MM,TT,GG)=DSQRT(MM*GG/TT)
      MDMU(GX,MXX)=DSQRT((MXX*MXX+2.0/(GX-1.0))/(2.0*GX*MXX*MXX
     -/(GX-1.0)-1.0))
      PDPUMU(GX,MXX)=(2.0*GX*MXX*MXX-GX+1.0)/(GX+1.0)
      PPOM(GX,MXX)=(1.0+0.5*(GX-1.0)*MXX*MXX)**(GX/(1.0-GX))
      AASM(GX,MXX)=((2.0*(1.0+0.5*(GX-1.0)*MXX*MXX)/(GX+1.0))**
     -(0.5*(GX+1.0)/(GX-1.0)))/MXX
C
C
C     ****************************************************************
C     *                                                              *
C     *                       INITIAL DATA                           *
C     *                                                              *
C     *  GS     = SECONDARY GAMMA                                    *
C     *  GP     = PRIMARY GAMMA                                      *
C     *  MWSMWP = SECONDARY-TO-PRIMARY MOLECULAR WEIGHT RATIO        *
C     *  TSOTPO = SECONDARY-TO-PRIMARY STAGNATION TEMPERATURE        *
C     *           RATIO                                              *
C     *  MS1    = SECONDARY MACH NO. AT STATION 1                    *
```

7.2.1 CASSE (Cont.)

```
C      *  MP1     = PRIMARY MACH NO. AT STATION 1                    *   CASSE  10100
C      *  AS1AP1  = SECONDARY-TO-PRIMARY AREA RATIO AT STATION 1     *   CASSE  10200
C      *  RD      = NORMAL SHOCK DIFFUSER COEFFICIENT                *   CASSE  10300
C      *  ERROR   = MAX PERCENT DEVIATION IN M(G,AAS)                *   CASSE  10400
C      *  NDATA   = NUMBER OF INCREMENTS INTO WHICH THE PLANE OF     *   CASSE  10500
C      *            OPERATION IS DIVIDED                             *   CASSE  10600
C      *                                                             *   CASSE  10700
C      ***************************************************************   CASSE  10800
C                                                                        CASSE  10900
C                                                                        CASSE  11000
       WRITE(5,200)                                                      CASSE  11100
       READ(5,201)GS,GP,MWSMWP,TSOTPO,MS1,MP1,AS1AP1                     CASSE  11200
       WRITE(5,202)                                                      CASSE  11300
       READ(5,203)RD,ERROR,NDATA                                         CASSE  11400
C                                                                        CASSE  11500
C                                                                        CASSE  11600
C      ***************************************************************   CASSE  11700
C      *                                                             *   CASSE  11800
C      *             CHECK CONSISTENCY OF INITIAL DATA               *   CASSE  11900
C      *                                                             *   CASSE  12000
C      ***************************************************************   CASSE  12100
C                                                                        CASSE  12200
C                                                                        CASSE  12300
       IF(MS1.LE.1.0) GO TO 105                                          CASSE  12400
       IF(MP1.LE.1.0) GO TO 106                                          CASSE  12500
C                                                                        CASSE  12600
C                                                                        CASSE  12700
C      ***************************************************************   CASSE  12800
C      *                                                             *   CASSE  12900
C      *                   OUTPUT - INITIAL DATA                     *   CASSE  13000
C      *                                                             *   CASSE  13100
C      ***************************************************************   CASSE  13200
C                                                                        CASSE  13300
C                                                                        CASSE  13400
       WRITE(3,300)                                                      CASSE  13500
       WRITE(3,301)GS,GP,MWSMWP,TSOTPO,MS1,MP1,AS1AP1,RD,ERROR,          CASSE  13600
      -NDATA                                                             CASSE  13700
C                                                                        CASSE  13800
C                                                                        CASSE  13900
C      ***************************************************************   CASSE  14000
C      *                                                             *   CASSE  14100
C      *                   CALCULATE CONSTANTS                       *   CASSE  14200
C      *                                                             *   CASSE  14300
C      ***************************************************************   CASSE  14400
C                                                                        CASSE  14500
C                                                                        CASSE  14600
       GP1=(GP-1.0)/2.0                                                  CASSE  14700
       GP1I=1.0/GP1                                                      CASSE  14800
       GP2=2.0/(GP+1.0)                                                  CASSE  14900
       GP2I=1.0/GP2                                                      CASSE  15000
```

```
      GS3=GS/(GS-1.0)                                                   CASSE  15100
      GP3=GP/(GP-1.0)                                                   CASSE  15200
      GP4=(GP+1.0)/(2.0*(GP-1.0))                                       CASSE  15300
      GP4I=1.0/GP4                                                      CASSE  15400
      GSGP=GS/GP                                                        CASSE  15500
      MWPMWS=1.0/MWSMWP                                                 CASSE  15600
      PS1PS0=PPOM(GS,MS1)                                               CASSE  15700
      PP1PP0=PPOM(GP,MP1)                                               CASSE  15800
      AS1ASS=AASM(GS,MS1)                                               CASSE  15900
      AP1APS=AASM(GP,MP1)                                               CASSE  16000
      ASSAS1=1.0/AS1ASS                                                 CASSE  16100
      FGSMS1=F(GS,MS1)                                                  CASSE  16200
      FGPMP1=F(GP,MP1)                                                  CASSE  16300
      GGSMS1=G(GS,MS1)                                                  CASSE  16400
      GGPMP1=G(GP,MP1)                                                  CASSE  16500
C                                                                       CASSE  16600
C                                                                       CASSE  16700
C     ***********************************************************       CASSE  16800
C     *                                                         *       CASSE  16900
C     *  CALCULATE PS1PP1(1) FOR AN ISENTROPIC RECOMPRESSION    *       CASSE  17000
C     *  OF THE SECONDARY STREAM TO SONIC CONDITIONS AT         *       CASSE  17100
C     *  STATION 2.  MP2 IS OBTAINED FROM AP2AP2 BY LINEAR      *       CASSE  17200
C     *  ITERATION.                                             *       CASSE  17300
C     *                                                         *       CASSE  17400
C     ***********************************************************       CASSE  17500
C                                                                       CASSE  17600
C                                                                       CASSE  17700
      AP2APS=AP1APS*(1.0+AS1AP1*(1.0-ASSAS1))                           CASSE  17800
      MP2=MP1                                                           CASSE  17900
      DO 100 I=1,200                                                    CASSE  18000
      C1=(MP2*AP2APS)**GP4I                                             CASSE  18100
      XMP2=DSQRT(GP1I*(GP2I*C1-1.0))                                    CASSE  18200
      XERROR=(XMP2-MP2)*100.0/MP2                                       CASSE  18300
      MP2=XMP2                                                          CASSE  18400
      IF(DABS(XERROR).LT.ERROR) GO TO 101                               CASSE  18500
100   CONTINUE                                                          CASSE  18600
      GO TO 107                                                         CASSE  18700
101   MS2=1.0                                                           CASSE  18800
      C1=-FGPMP1+F(GP,MP2)*GGPMP1/G(GP,MP2)                             CASSE  18900
      C2=FGSMS1-F(GS,MS2)*GGSMS1/G(GS,MS2)                              CASSE  19000
      PS1PP1(1)=C1/(AS1AP1*C2)                                          CASSE  19100
C                                                                       CASSE  19200
C                                                                       CASSE  19300
C     ***********************************************************       CASSE  19400
C     *                                                         *       CASSE  19500
C     *  DIVIDE THE PLANE OF OPERATION INTO NDATA INCREMENTS    *       CASSE  19600
C     *  FROM PS1PP1(1) TO PS1PP1=1.0, THE MATCHED PRESSURE     *       CASSE  19700
C     *  CONDITION.                                             *       CASSE  19800
C     *                                                         *       CASSE  19900
C     ***********************************************************       CASSE  20000
```

7.2.1 CASSE (Cont.)

```
C                                                                 CASSE  20100
C                                                                 CASSE  20200
      C1=(1.0-FS1PP1(1))/NDATA                                    CASSE  20300
      NDATA=NDATA+1                                               CASSE  20400
      DO 102 I=2,NDATA                                            CASSE  20500
  102 PS1PP1(I)=PS1PP1(1)+(I-1)*C1                                CASSE  20600
C                                                                 CASSE  20700
C                                                                 CASSE  20800
C     ************************************************************CASSE  20900
C     *                                                          *CASSE  21000
C     *          OVERALL CONTROL VOLUME CALCULATIONS             *CASSE  21100
C     *                                                          *CASSE  21200
C     ************************************************************CASSE  21300
C                                                                 CASSE  21400
C                                                                 CASSE  21500
      DO 104 I=1,NDATA                                            CASSE  21600
      WSWP(I)=PS1PP1(I)*AS1AP1*H(MWSMWP,TSOTPO,GSGP)*GGSMS1       CASSE  21700
     -/GGPMP1                                                     CASSE  21800
      WPWS(I)=1.0/WSWP(I)                                         CASSE  21900
      C1=WSWP(I)*MWPMWS*GS3+GP3                                   CASSE  22000
      C2=WSWP(I)*MWPMWS*(GS3-1.0)+(GP3-1.0)                       CASSE  22100
      GM(I)=C1/C2                                                 CASSE  22200
      GMGP=GM(I)/GP                                               CASSE  22300
      MWMMWP(I)=(WSWP(I)+1.0)/(WSWP(I)*MWPMWS+1.0)                CASSE  22400
      MWMMWS(I)=MWMMWP(I)*MWPMWS                                  CASSE  22500
      C1=TSOTPO*WSWP(I)*MWPMWS*GS3+GP3                            CASSE  22600
      C2=WSWP(I)*MWPMWS*GS3+GP3                                   CASSE  22700
      TMOTPO(I)=C1/C2                                             CASSE  22800
      TMOTSO(I)=TMOTPO(I)/TSOTPO                                  CASSE  22900
      FFX=F(MWMMWP(I),TMOTPO(I),GMGP)*(PS1PP1(I)*AS1AP1*FGSMS1    CASSE  23000
     -+FGPMP1)/((1.0+WSWP(I))*GGPMP1)                             CASSE  23100
      C1=0.5*(GM(I)-1.0)*FFX*FFX-GM(I)*GM(I)                      CASSE  23200
      C2=FFX*FFX-2.0*GM(I)                                        CASSE  23300
      C3=(-C2+DSQRT(C2*C2+4.0*C1))/(2.0*C1)                       CASSE  23400
      C4=(-C2-DSQRT(C2*C2+4.0*C1))/(2.0*C1)                       CASSE  23500
C                                                                 CASSE  23600
C                                                                 CASSE  23700
C     ************************************************************CASSE  23800
C     *                                                          *CASSE  23900
C     *     IDENTIFY THE SUPERSONIC AND SUBSONIC SOLUTIONS       *CASSE  24000
C     *                                                          *CASSE  24100
C     ************************************************************CASSE  24200
C                                                                 CASSE  24300
C                                                                 CASSE  24400
      MM3(I,1)=DSQRT(DMIN1(C3,C4))                                CASSE  24500
      MM3(I,2)=DSQRT(DMAX1(C3,C4))                                CASSE  24600
      DO 103 J=1,2                                                CASSE  24700
      PM3PP1=(PS1PP1(I)*AS1AP1*FGSMS1+FGPMP1)/((1.0+AS1AP1)       CASSE  24800
     -*F(GM(I),MM3(I,J)))                                         CASSE  24900
      PM3PS1(I,J)=PM3PP1/PS1PP1(I)                                CASSE  25000
```

```
      PM3PSO(I,J)=PM3PF1*PS1PSO/PS1PP1(I)
  103 PM3PPO(I,J)=PM3PF1*PP1PPO
      PP1PS1(I)=1.0/PS1PP1(I)
      PS1PPO(I)=PS1PP1(I)*PP1PPO
      PPOPS1(I)=1.0/PS1PPO(I)
      PSOPPO(I)=PS1PP1(I)*PP1PPO/PS1PSO
      PPOPSO(I)=1.0/PSOPPO(I)
C
C
C     ***********************************************************
C     *                                                         *
C     *  DIFFUSE THE SUPERSONIC SOLUTION TO RD OF NORMAL SHOCK  *
C     *  CONDITIONS                                             *
C     *                                                         *
C     ***********************************************************
C
C
      C1=RD*PDPUMU(GM(I),MM3(I,2))
      PM3PS1(I,3)=C1*PM3PS1(I,2)
      PM3PSO(I,3)=C1*PM3PSO(I,2)
      PM3PPO(I,3)=C1*PM3PPO(I,2)
  104 MM3(I,3)=RDMU(GM(I),MM3(I,2))
C
C
C     ***********************************************************
C     *                                                         *
C     *              OUTPUT - SUBSONIC SOLUTION                 *
C     *                                                         *
C     ***********************************************************
C
C
      WRITE(3,302)
      WRITE(3,303)
      WRITE(3,304)(I,PS1PP1(I),PS1PPO(I),PSOPPO(I),WSWP(I),
     -PM3PPO(I,1),MM3(I,1),I=1,NDATA)
      WRITE(3,305)
      WRITE(3,306)(I,PP1PS1(I),PPOPS1(I),PPOPSO(I),WPWS(I),
     -PM3PSO(I,1),PM3PS1(I,1),MM3(I,1),I=1,NDATA)
C
C
C     ***********************************************************
C     *                                                         *
C     *             OUTPUT - SUPERSONIC SOLUTION                *
C     *                                                         *
C     ***********************************************************
C
C
      WRITE(3,307)
      WRITE(3,303)
      WRITE(3,304)(I,PS1PP1(I),PS1PPO(I),PSOPPO(I),WSWP(I),
```

7.2.1 CASSE (Cont.)

```
     -PM3PPO(I,2),MM3(I,2),I=1,NDATA)                                   CASSE  30100
      WRITE(3,305)                                                      CASSE  30200
      WRITE(3,306)(I,PP1PS1(I),PPOPS1(I),PPOPSO(I),WPWS(I),             CASSE  30300
     -PM3PSO(I,2),PM3PS1(I,2),MM3(I,2),I=1,NDATA)                       CASSE  30400
C                                                                       CASSE  30500
C                                                                       CASSE  30600
C     ***************************************************************   CASSE  30700
C     *                                                             *   CASSE  30800
C     *   OUTPUT - SUPERSONIC SOLUTION AT RD OF NORMAL SHOCK        *   CASSE  30900
C     *   CONDITIONS                                                *   CASSE  31000
C     *                                                             *   CASSE  31100
C     ***************************************************************   CASSE  31200
C                                                                       CASSE  31300
C                                                                       CASSE  31400
      WRITE(3,308)RD                                                    CASSE  31500
      WRITE(3,303)                                                      CASSE  31600
      WRITE(3,304)(I,PS1PP1(I),PS1PPO(I),PSOPPO(I),WSWP(I),             CASSE  31700
     -PM3PPO(I,3),MM3(I,3),I=1,NDATA)                                   CASSE  31800
      WRITE(3,305)                                                      CASSE  31900
      WRITE(3,306)(I,PP1PS1(I),PPOPS1(I),PPOPSO(I),WPWS(I),             CASSE  32000
     -PM3PSO(I,3),PM3PS1(I,3),MM3(I,3),I=1,NDATA)                       CASSE  32100
C                                                                       CASSE  32200
C                                                                       CASSE  32300
C     ***************************************************************   CASSE  32400
C     *                                                             *   CASSE  32500
C     *                 OUTPUT - MIXED PROPERTIES                   *   CASSE  32600
C     *                                                             *   CASSE  32700
C     ***************************************************************   CASSE  32800
C                                                                       CASSE  32900
C                                                                       CASSE  33000
      WRITE(3,309)                                                      CASSE  33100
      WRITE(3,310)                                                      CASSE  33200
      WRITE(3,306)(I,PS1PP1(I),PS1PPO(I),PSOPPO(I),WSWP(I),             CASSE  33300
     -MWMMWP(I),TMOTPO(I),GM(I),I=1,NDATA)                              CASSE  33400
      WRITE(3,311)                                                      CASSE  33500
      WRITE(3,306)(I,PP1PS1(I),PPOPS1(I),PPOPSO(I),WPWS(I),             CASSE  33600
     -MWMMWS(I),TMOTSO(I),GM(I),I=1,NDATA)                              CASSE  33700
      STOP                                                              CASSE  33800
C                                                                       CASSE  33900
C                                                                       CASSE  34000
C     ***************************************************************   CASSE  34100
C     *                                                             *   CASSE  34200
C     *                    FAILURE INDICATORS                       *   CASSE  34300
C     *                                                             *   CASSE  34400
C     ***************************************************************   CASSE  34500
C                                                                       CASSE  34600
C                                                                       CASSE  34700
  105 WRITE(5,400)MS1                                                   CASSE  34800
      STOP                                                              CASSE  34900
  106 WRITE(5,401)MP1                                                   CASSE  35000
```

```
      STOP
107   WRITE(5,402)MP2,XERROR,ERROR
      STOP
C
C
C     ***********************************************************
C     *                                                         *
C     *                  FORMAT STATEMENTS                      *
C     *                                                         *
C     ***********************************************************
C
C
200   FORMAT('0',T2,'INPUT GS,GP,MWSMWP,TSOTPO,MS1,MP1,AS1AP1')
201   FORMAT(7F)
202   FORMAT('0',T2,'INPUT RC,ERROR,NDATA')
203   FORMAT(F,D,I)
C
300   FORMAT('1',T44,'CONSTANT-AREA SUPERSONIC-SUPERSONIC ',
     -'EJECTOR',/,T46,'PLANE OF SUPERSONIC-SUPERSONIC ',
     -'OPERATION',/,T54,'ONE-DIMENSIONAL ANALYSIS',//,T59,
     -'C.D. MIKKELSEN',/,T61,'9 MARCH 75',//,T49,'MECHANICAL ',
     -'ENGINEERING DEPARTMENT',/,T45,'UNIVERSITY OF ILLINOIS ',
     -'AT URBANA-CHAMPAIGN',/,T55,'URBANA, ILLINOIS 61801')
301   FORMAT('C',T44,'GS      =',D13.6,T67,'GP      =',D13.6,/,
     -T44,'MWSMW  =',D13.6,T67,'TSOTPO =',D13.6,/,
     -T44,'MS1    =',D13.6,T67,'MP1    =',D13.6,/,
     -T44,'AS1AP1 =',D13.6,T67,'RD     =',D13.6,/,
     -T44,'ERROR  =',D13.6,T67,'NDATA  =',I13)
302   FORMAT('0',T57,'SUBSONIC SOLUTIONS')
303   FORMAT('0',T15,'NO',T22,'PS1PP1',T36,'PS1PP0',T50,
     -'PSOPPO',T65,'WSWP',T78,'PM3PPO',T108,'MM3',/)
304   FORMAT(' ',T15,I2,5D14.6,T101,D14.6)
305   FORMAT('0',T15,'NC',T22,'PP1PS1',T36,'PPOPS1',T50,
     -'PPOPSO',T65,'WPWS',T78,'PM3PSO',T92,'PM3PS1',T108,
     -'MM3',/)
306   FORMAT(' ',T15,I2,7D14.6)
307   FORMAT('1',T56,'SUPERSCNIC SOLUTIONS')
308   FORMAT('1',T38,'SUPERSCNIC SOLUTIONS AT',F6.3,
     -' OF NORMAL SHOCK CONDITIONS')
309   FORMAT('1',T58,'MIXED PROPERITIES')
310   FORMAT('0',T15,'NO',T22,'PS1PP1',T36,'PS1PP0',T50,
     -'PSOPPO',T65,'WSWP',T78,'MWMMWP',T92,'TMOTPO',T108,'GM',/)
311   FORMAT('0',T15,'NO',T22,'PP1PS1',T36,'PPOPS1',T50,
     -'PPOPSO',T65,'WPWS',T78,'MWMMWS',T92,'TMOTSO',T108,'GM',/)
C
400   FORMAT('0','INPUT ERROR: MS1 =',E13.6,2X,'MS1 MUST BE ',
     -'SUPERSCNIC')
401   FORMAT('0','INPUT ERROR: MP1 =',E13.6,2X,'MP1 MUST BE ',
     -'SUPERSONIC')
402   FORMAT('0',T2,'CONVERGENCE FAILURE',/,T2,'MP2 =',E13.6,2X,
```

```
     -'XERROR =',E13.6,2X,'ERROR =',E13.6)                          CASSE  40100
      END                                                           CASSE  40200
```

7.2.2 CASSE Sample Input

```
INPUT GS,GP,MWSMWP,TSOTPO,MS1,MP1,AS1AP1
1.562, 1.34, 0.593912, 1.31341, 2.18, 4.690, 4.02823

INPUT RD,ERROR,NDATA
0.75, 5.0E-06, 10
```

7.2.3. CASSE Sample Output

```
CONSTANT-AREA SUPERSONIC-SUPERSONIC EJECTOR
PLANE OF SUPERSONIC-SUPERSONIC OPERATION
ONE-DIMENSIONAL ANALYSIS

C.D. MIKKELSEN
9 MARCH 75

MECHANICAL ENGINEERING DEPARTMENT
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
URBANA, ILLINOIS 61801

GS     = 0.156200D+01   GP     = 0.134000D+01
MWSMWP = 0.593912D+00   TSOTPO = 0.131341D+01
MS1    = 0.218000D+01   MP1    = 0.469000D+01
AS1AP1 = 0.402823D+01   RD     = 0.750000D+00
ERROR  = 0.500000D-05   NDATA  =          10

SUBSONIC SOLUTIONS
```

NO	PS1PP1	PS1PP0	PSOPP0	WSWP	PM3PP0	MM3
1	0.237707D+00	0.516320D-03	0.545432D-02	0.226836D+00	0.132029D-01	0.434615D+00
2	0.313936D+00	0.681897D-03	0.720344D-02	0.299580D+00	0.139613D-01	0.442472D+00
3	0.390165D+00	0.847474D-03	0.895257D-02	0.372323D+00	0.147178D-01	0.449454D+00
4	0.466395D+00	0.101305D-02	0.107017D-01	0.445066D+00	0.154725D-01	0.455703D+00
5	0.542624D+00	0.117863D-02	0.124508D-01	0.517810D+00	0.162258D-01	0.461330D+00
6	0.618853D+00	0.134420D-02	0.141999D-01	0.590553D+00	0.169779D-01	0.466425D+00
7	0.695083D+00	0.150978D-02	0.159491D-01	0.663296D+00	0.177288D-01	0.471062D+00
8	0.771312D+00	0.167536D-02	0.176982D-01	0.736040D+00	0.184788D-01	0.475301D+00
9	0.847541D+00	0.184094D-02	0.194473D-01	0.803783D+00	0.192280D-01	0.479192D+00
10	0.923771D+00	0.200651D-02	0.211964D-01	0.881526D+00	0.199765D-01	0.482776D+00
11	0.100000D+01	0.217209D-02	0.229456D-01	0.954269D+00	0.207243D-01	0.486089D+00

NO	PP1PS1	PP0PS1	PP0PS0	WPWS	PM3PS0	PM3PS1	MM3
1	0.420686D+01	0.193678D+04	0.183341D+03	0.440847D+01	0.242063D+01	0.255711D+02	0.434615D+00
2	0.318536D+01	0.146650D+04	0.138823D+03	0.333801D+01	0.193815D+01	0.204743D+02	0.442472D+00
3	0.256302D+01	0.117998D+04	0.111700D+03	0.268584D+01	0.164397D+01	0.173666D+02	0.449454D+00
4	0.214411D+01	0.987117D+03	0.934432D+02	0.224686D+01	0.144530D+01	0.152732D+02	0.455703D+00
5	0.184290D+01	0.848444D+03	0.803160D+02	0.193121D+01	0.130319D+01	0.137667D+02	0.461330D+00
6	0.161589D+01	0.743934D+03	0.704228D+02	0.169333D+01	0.119563D+01	0.126304D+02	0.466425D+00
7	0.143868D+01	0.662347D+03	0.626996D+02	0.150762D+01	0.111159D+01	0.117426D+02	0.471062D+00
8	0.129649D+01	0.596887D+03	0.565030D+02	0.135862D+01	0.104411D+01	0.110298D+02	0.475301D+00
9	0.117988D+01	0.543202D+03	0.514210D+02	0.123643D+01	0.988724D+00	0.104447D+02	0.479192D+00
10	0.108252D+01	0.498377D+03	0.471777D+02	0.113440D+01	0.942446D+00	0.995583D+01	0.482776D+00
11	0.100000D+01	0.460386D+03	0.435814D+02	0.104792D+01	0.903194D+00	0.954118D+01	0.486089D+00

7.2.3 CASSE Sample Output (Cont.)

SUPERSONIC SOLUTIONS

NO	PS1PP1	PS1PP0	PS0PP0	WSWP	PM3PP0	MM3
1	0.237707D+00	0.516320D-03	0.545432D-02	0.226836D+00	0.777751D-03	0.384307D+01
2	0.313936D+00	0.681897D-03	0.720344D-02	0.299580D+00	0.893705D-03	0.368285D+01
3	0.390165D+00	0.847474D-03	0.895257D-02	0.372323D+00	0.101142D-02	0.355134D+01
4	0.466395D+00	0.101305D-02	0.107017D-01	0.445066D+00	0.113064D-02	0.344136D+01
5	0.54262[illegible]D+00	0.117863D-02	0.124508D-01	0.517810D+00	0.125112D-02	0.334797D+01
6	0.618853D+00	0.134420D-02	0.141999D-01	0.590553D+00	0.137270D-02	0.326764D+01
7	0.695083D+00	0.150978D-02	0.159491D-01	0.663296D+00	0.149523D-02	0.319779D+01
8	0.771312D+00	0.167536D-02	0.176982D-01	0.736040D+00	0.161859D-02	0.313648D+01
9	0.847541D+00	0.184094D-02	0.194473D-01	0.808783D+00	0.174268D-02	0.308221D+01
10	0.923771D+00	0.200651D-02	0.211964D-01	0.881526D+00	0.186741D-02	0.303383D+01
11	0.100000D+01	0.217209D-02	0.229456D-01	0.954269D+00	0.199272D-02	0.299043D+01

NO	PP1PS1	PF0PS1	PP0PS0	WPWS	PM3PS0	PM3PS1	MM3
1	0.420686D+01	0.193678D+04	0.183341D+03	0.440847D+01	0.142594D+00	0.150633D+01	0.384307D+01
2	0.318536D+01	0.146650D+04	0.138823D+03	0.333601D+01	0.124066D+00	0.131061D+01	0.368285D+01
3	0.256302D+01	0.117998D+04	0.111700D+03	0.268584D+01	0.112976D+00	0.119346D+01	0.355134D+01
4	0.214411D+01	0.987117D+03	0.934432D+02	0.224686D+01	0.105650D+00	0.111607D+01	0.344136D+01
5	0.184290D+01	0.848444D+03	0.803160D+02	0.193121D+01	0.100485D+00	0.106150D+01	0.334797D+01
6	0.161589D+01	0.743934D+03	0.704228D+02	0.169333D+01	0.966693D-01	0.102120D+01	0.326764D+01
7	0.143868D+01	0.662347D+03	0.626996D+02	0.150762D+01	0.937501D-01	0.990360D+00	0.319779D+01
8	0.129649D+01	0.596887D+03	0.565030D+02	0.135862D+01	0.914549D-01	0.966113D+00	0.313648D+01
9	0.117988D+01	0.543202D+03	0.514210D+02	0.123643D+01	0.896101D-01	0.946625D+00	0.308221D+01
10	0.108252D+01	0.498377D+03	0.471777D+02	0.113440D+01	0.881002D-01	0.930675D+00	0.303383D+01
11	0.100000D+01	0.460386D+03	0.435814D+02	0.104792D+01	0.868455D-01	0.917420D+00	0.299043D+01

7.2.3 CASSE Sample Output (Cont.)

SUPERSONIC SOLUTIONS AT 0.750 OF NORMAL SHOCK CONDITIONS

NO	PS1PP1	PS1PP0	PS0PP0	WSWP	PM3PP0	MM3
1	0.237707D+00	0.516320D-03	0.545432D-02	0.226836D+00	0.990217D-02	0.434615D+00
2	0.313936D+00	0.681897D-03	0.720344D-02	0.299580D+00	0.104710D-01	0.442472D+00
3	0.390165D+00	0.847474D-03	0.895257D-02	0.372323D+00	0.110383D-01	0.449454D+00
4	0.466395D+00	0.101305D-02	0.107017D-01	0.445066D+00	0.116044D-01	0.455703D+00
5	0.542624D+00	0.117863D-02	0.124508D-01	0.517810D+00	0.121694D-01	0.461330D+00
6	0.618853D+00	0.134420D-02	0.141999D-01	0.590553D+00	0.127334D-01	0.466425D+00
7	0.695083D+00	0.150978D-02	0.159491D-01	0.663296D+00	0.132966D-01	0.471062D+00
8	0.771312D+00	0.167536D-02	0.176982D-01	0.736040D+00	0.138591D-01	0.475301D+00
9	0.847541D+00	0.184094D-02	0.194473D-01	0.808783D+00	0.144210D-01	0.479192D+00
10	0.923771D+00	0.200651D-02	0.211964D-01	0.881526D+00	0.149824D-01	0.482776D+00
11	0.100000D+01	0.217209D-02	0.229456D-01	0.954269D+00	0.155432D-01	0.486089D+00

NO	PP1PS1	PP0PS1	PP0PS0	WPWS	PM3PS0	PM3PS1	MM3
1	0.420686D+01	0.193678D+04	0.183341D+03	0.440847D+01	0.181547D+01	0.191783D+02	0.434615D+00
2	0.318536D+01	0.146650D+04	0.138823D+03	0.333801D+01	0.145361D+01	0.153557D+02	0.442472D+00
3	0.256302D+01	0.117998D+04	0.111700D+03	0.268584D+01	0.123298D+01	0.130250D+02	0.449454D+00
4	0.214411D+01	0.987117D+03	0.934432D+02	0.224686D+01	0.108435D+01	0.114549D+02	0.455703D+00
5	0.184290D+01	0.848444D+03	0.803160D+02	0.193121D+01	0.977395D+00	0.103250D+02	0.461330D+00
6	0.161589D+01	0.743934D+03	0.704228D+02	0.169333D+01	0.896722D+00	0.947281D+01	0.466425D+00
7	0.143868D+01	0.662347D+03	0.626996D+02	0.150762D+01	0.833693D+00	0.880698D+01	0.471062D+00
8	0.129649D+01	0.596887D+03	0.565030D+02	0.135862D+01	0.783082D+00	0.827234D+01	0.475301D+00
9	0.117988D+01	0.543202D+03	0.514210D+02	0.123643D+01	0.741530D+00	0.783353D+01	0.479192D+00
10	0.108252D+01	0.498377D+03	0.471777D+02	0.113440D+01	0.706834D+00	0.746687D+01	0.482776D+00
11	0.100000D+01	0.460386D+03	0.435814D+02	0.104792D+01	0.677396D+00	0.715589D+01	0.486089D+00

7.2.3 CASSE Sample Output (Cont.)

MIXED PROPERTIES

NO	PS1PP1	PS1PPO	PSOPPO	WSWP	MWMMWP	TMOTPO	GM
1	0.237707D+00	0.516320D-03	0.545432D-02	0.226836D+00	0.887766D 00	0.106650D+01	0.138167D+01
2	0.313936D+00	0.681897D-03	0.720344D-02	0.299580D+00	0.863842D+00	0.108223D+01	0.139191D+01
3	0.390165D+00	0.847474D-03	0.895257D-02	0.372323D+00	0.843521D+00	0.109608D+01	0.140104D+01
4	0.466395D+00	0.101305D-02	0.107017D-01	0.445066D+00	0.826044D+00	0.110836D+01	0.140925D+01
5	0.542624D+00	0.117863D-02	0.124508D-01	0.517810D+00	0.810655D+00	0.111933D+01	0.141666D+01
6	0.618853D+00	0.134420D-02	0.141999D-01	0.590553D+00	0.797532D+00	0.112918D+01	0.142339D+01
7	0.695083D+00	0.150978D-02	0.159491D-01	0.663296D+00	0.785750D+00	0.113809D+01	0.142951D+01
8	0.771312D+00	0.167536D-02	0.176982D-01	0.736040D+00	0.775257D+00	0.114617D+01	0.143513D+01
9	0.847541D+00	0.184094D-02	0.194473D-01	0.808783D+00	0.765853D+00	0.115354D+01	0.144028D+01
10	0.923771D+00	0.200651D-02	0.211964D-01	0.881526D+00	0.757376D+00	0.116028D+01	0.144503D+01
11	0.100000D+01	0.217209D-02	0.229456D-01	0.954269D+00	0.749595D+00	0.116648D+01	0.144943D+01

NO	PP1PS1	PPOPS1	PFOPSO	WPWS	MWMMWS	TMOTSO	GM
1	0.420686D+01	0.193678D+04	0.183341D+03	0.440847D+01	0.149478D+01	0.812011D+00	0.138167D+01
2	0.318536D+01	0.146650D+04	0.138823D+03	0.333801D+01	0.145450D+01	0.823988D+00	0.139191D+01
3	0.256302D+01	0.117998D+04	0.111700D+03	0.268584D+01	0.142028D+01	0.834530D+00	0.140104D+01
4	0.214411D+01	0.987117D+03	0.934432D+02	0.224686D+01	0.139085D+01	0.843881D+00	0.140925D+01
5	0.184290D+01	0.848444D+03	0.803160D+02	0.193121D+01	0.136528D+01	0.852232D+00	0.141666D+01
6	0.161589D+01	0.743934D+03	0.704228D+02	0.169333D+01	0.134285D+01	0.859734D+00	0.142339D+01
7	0.143868D+01	0.662347D+03	0.626996D+02	0.150762D+01	0.132301D+01	0.866512D+00	0.142951D+01
8	0.129649D+01	0.596887D+03	0.565030D+02	0.135862D+01	0.130534D+01	0.872665D+00	0.143513D+01
9	0.117988D+01	0.543202D+03	0.514210D+02	0.123643D+01	0.128951D+01	0.878275D+00	0.144028D+01
10	0.108252D+01	0.498377D+03	0.471777D+02	0.113440D+01	0.127523D+01	0.883412D+00	0.144503D+01
11	0.100000D+01	0.460386D+03	0.435814D+02	0.104792D+01	0.126230D+01	0.888133D+00	0.144943D+01

7.3 CONSTANT-AREA SUPERSONIC-SUPERSONIC EJECTOR PARAMETERS COMPUTER PROGRAM

7.3.1 Computer Program (CASSEP)

```
C     ********************************************************     CASSEP 00100
C     *                                                      *     CASSEP 00200
C     *        CONSTANT-AREA SUPERSONIC-SUPERSONIC           *     CASSEP 00300
C     *            EJECTOR PARAMETERS (CASSEP               *     CASSEP 00400
C     *                                                      *     CASSEP 00500
C     *                  C.D. MIKKELSEN                      *     CASSEP 00600
C     *                    1 MAY 75                          *     CASSEP 00700
C     *                                                      *     CASSEP 00800
C     *          MECHANICAL ENGINEERING DEPARTMENT           *     CASSEP 00900
C     *     UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN       *     CASSEP 01000
C     *              URBANA, ILLINOIS 61801                  *     CASSEP 01100
C     *                                                      *     CASSEP 01200
C     *  CASSEP IS A PROGRAM FOR EVALUATING THE INFLUENCE OF *     CASSEP 01300
C     *  CONSTANT-AREA SUPERSONIC-SUPERSONIC EJECTOR         *     CASSEP 01400
C     *  PARAMETERS ON THE PLANE OF OPERATION AS CALCULATED BY *   CASSEP 01500
C     *  ONE-DIMENSIONAL ANALYSIS.  THE MAXIMUM COMPRESSION  *     CASSEP 01600
C     *  RATIO IS CALCULATED AT THE UPPER AND LOWER LIMITS OF *    CASSEP 01700
C     *  THE PLANE WITH VARIATIONS IN THE SELECTED EJECTOR   *     CASSEP 01800
C     *  PARAMETER.  CASSEP IS A FORTRAN IV PROGRAM WRITTEN  *     CASSEP 01900
C     *  FOR DEC SYSTEM-10 (F40).                            *     CASSEP 02000
C     *                                                      *     CASSEP 02100
C     ********************************************************     CASSEP 02200
C                                                                  CASSEP 02300
C     ********************************************************     CASSEP 02400
C     *                                                      *     CASSEP 02500
C     *                  GENERAL NOTATION                    *     CASSEP 02600
C     *                                                      *     CASSEP 02700
C     * CATALG(I) = ALPHANUMERIC CATALOG OF EJECTOR PARAMETERS *   CASSEP 02800
C     * TITLE(I)  = ALPHANUMERIC CATALOG OF EJECTOR PARAMETERS *   CASSEP 02900
C     *             FOR WRITING COLUMN HEADINGS              *     CASSEP 03000
C     * VARBLE    = ALPHANUMERIC IMAGE OF THE INDEPENDENT    *     CASSEP 03100
C     *             VARIABLE AS SELECTED FROM CATALG         *     CASSEP 03200
C     * INDVAR    = NUMERICAL LOCATION OF VARBLE IN CATALG AND *   CASSEP 03300
C     *             TITLE                                    *     CASSEP 03400
C     * LIST(I)   = NUMERICAL SEQUENCE IN WHICH THE EJECTOR  *     CASSEP 03500
C     *             PARAMETERS ARE TO BE READ AND WRITTEN    *     CASSEP 03600
C     * X(I)      = NUMERICAL VALUE OF THE EJECTOR PARAMETERS *    CASSEP 03700
C     * Y(I)      = NUMERICAL VALUE OF VARBLE                *     CASSEP 03800
C     *                                                      *     CASSEP 03900
C     *                  EJECTOR NOTATION                    *     CASSEP 04000
C     *                                                      *     CASSEP 04100
C     * ERROR  = MAX PERCENT DEVIATION IN M(G,ASS)           *     CASSEP 04200
C     * FLOW   = "UL" FOR AN ISENTROPIC RECOMPRESSION OF THE *     CASSEP 04300
C     *          SECONDARY STREAM TO SONIC CONDITIONS, THE   *     CASSEP 04400
C     *          UPPER LIMIT OF THE PLANE OF OPERATION       *     CASSEP 04500
C     *        = "MP" FOR MATCHED PRESSURE CONDITIONS, THE   *     CASSEP 04600
C     *          LOWER LIMIT OF THE PLANE OF OPERATION       *     CASSEP 04700
C     * FAIL   = ERROR FLAG                                  *     CASSEP 04800
C     *                                                      *     CASSEP 04900
C     *  OTHER EJECTOR NOTATION IS GIVEN IN SUBROUTINE CASSE. *    CASSEP 05000
```

```
C      *                                                             *
C      ***************************************************************
C
C
       IMPLICIT REAL*8(A-H,M,O-Z)
C
       DIMENSION CATALG(8),FLOW(2),LIST(8),TITLE(8),X(8),Y(51)
C
       COMMON/BLOCK1/MM3(51,2,3),PM3PP0(51,2,3),PM3PS0(51,2,3),
      -PM3PS1(51,2,3)
       COMMON/BLOCK2/GM(51,2),MWMMWP(51,2),MWMMWS(51,2),
      -PSOPP0(51,2),PS1PP0(51,2),PS1PP1(51,2),PPOPS0(51,2),
      -PPOPS1(51,2),PP1PS1(51,2),TMOTP0(51,2),TMOTS0(51,2),
      -WPWS(51,2),WSWP(51,2)
       COMMON/BLOCK3/GS,GP,MWSMWP,TSOTPO,MS1,MP1,AS1AP1,RD,ERROR,
      -FAIL,I
C
       EQUIVALENCE (X(1),GS),(X(2),GP),(X(3),MWSMWP),(X(4),
      -TSOTPO),(X(5),MS1),(X(6),MP1),(X(7),AS1AP1),(X(8),RD)
C
       DATA CATALG/'GS    ','GP    ','MWSMWP','TSOTPO','MS1   ',
      -'MP1   ','AS1AP1','RD    '/
       DATA TITLE/'  GS  ','  GP  ','MWSMWP','TSOTPO','  MS1 ',
      -'  MP1 ','AS1AP1','  RD  '/
       DATA FLOW/'   UL ','   MP '/,FAIL/'NO    '/,YES/'YES   '/
C
C
C      ***************************************************************
C      *                                                             *
C      *              INDEPENDENT VARIABLE SELECTION                 *
C      *                                                             *
C      *  THE INDEPENDENT VARIABLE IS SELECTED FROM THE              *
C      *  FOLLOWING CATALOG OF EJECTOR PARAMETERS AND IS INPUT       *
C      *  TO THE PROGRAM AS ITS ALPHANUMERIC IMAGE.                  *
C      *                                                             *
C      *  GS     = SECONDARY GAMMA                                   *
C      *  GP     = PRIMARY GAMMA                                     *
C      *  MWSMWP = SECONDARY-TO-PRIMARY MOLECULAR WEIGHT RATIO       *
C      *  TSOTPO = SECONDARY-TO-PRIMARY STAGNATION TEMPERATURE       *
C      *           RATIO                                             *
C      *  MS1    = SECONDARY MACH NO. AT STATION 1                   *
C      *  MP1    = PRIMARY MACH NO. AT STATION 1                     *
C      *  AS1AP1 = SECONDARY-TO-PRIMARY AREA RATIO AT STATION 1      *
C      *  RD     = NORMAL SHOCK DIFFUSER COEFFICIENT                 *
C      *                                                             *
C      ***************************************************************
C
C
100    WRITE(5,200)
       READ(5,201)VARBLE
```

7.3.1 CASSEP (Cont.)

```
      DO 101 K=1,8                                                      CASSEP 10100
      IF(VARBLE.EQ.CATALG(K)) GO TO 102                                 CASSEP 10200
  101 CONTINUE                                                          CASSEP 10300
      GO TO 107                                                         CASSEP 10400
  102 INDVAR=K                                                          CASSEP 10500
C                                                                       CASSEP 10600
C                                                                       CASSEP 10700
C     ***********************************************************       CASSEP 10800
C     *                                                         *       CASSEP 10900
C     *            DETERMINE THE READ/WRITE SEQUENCE            *       CASSEP 11000
C     *                                                         *       CASSEP 11100
C     ***********************************************************       CASSEP 11200
C                                                                       CASSEP 11300
C                                                                       CASSEP 11400
      LIST(1)=INDVAR                                                    CASSEP 11500
      K=1                                                               CASSFP 11600
      DO 103 L=2,8                                                      CASSEP 11700
      IF(K.EQ.INDVAR) K=K+1                                             CASSEP 11800
      LIST(L)=K                                                         CASSEP 11900
  103 K=K+1                                                             CASSEP 12000
C                                                                       CASSEP 12100
C                                                                       CASSEP 12200
C     ***********************************************************       CASSEP 12300
C     *                                                         *       CASSEP 12400
C     *          INFUT - EJECTOR PARAMETERS AND ERROR           *       CASSEP 12500
C     *                                                         *       CASSEP 12600
C     ***********************************************************       CASSEP 12700
C                                                                       CASSEP 12800
C                                                                       CASSEP 12900
      WRITE(5,202)(CATALG(LIST(K)),K=2,8)                               CASSEP 13000
      READ(5,203)(X(LIST(K)),K=2,8),ERROR                               CASSEP 13100
      WRITE(5,204)CATALG(INDVAR)                                        CASSEP 13200
      READ(5,205)XLOW,DELX,XHIGH                                        CASSEP 13300
C                                                                       CASSEP 13400
C                                                                       CASSEP 13500
C     ***********************************************************       CASSEP 13600
C     *                                                         *       CASSEP 13700
C     *              PERFORM EJECTOR CALCULATIONS               *       CASSEP 13800
C     *                                                         *       CASSEP 13900
C     ***********************************************************       CASSEP 14000
C                                                                       CASSEP 14100
C                                                                       CASSEP 14200
      DO 104 I=1,52                                                     CASSEP 14300
      X(INDVAR)=XLOW+(I-1)*DELX                                         CASSEP 14400
      IF(X(INDVAR).GT.XHIGH) GO TO 105                                  CASSEP 14500
      Y(I)=X(INDVAR)                                                    CASSEP 14600
      CALL CASSE                                                        CASSEP 14700
  104 IF(FAIL.EQ.YES) GO TO 108                                         CASSEP 14800
      GO TO 109                                                         CASSEP 14900
  105 I=I-1                                                             CASSEP 15000
```

7.3.1 CASSEP (Cont.)

```
C
C
C     **********************************************************
C     *                                                        *
C     *              OUTPUT - INITIAL DATA                     *
C     *                                                        *
C     **********************************************************
C
C
      WRITE(3,300)
      WRITE(3,301)(CATALG(LIST(K)),X(LIST(K)),K=2,8),ERROR
C
C
C     **********************************************************
C     *                                                        *
C     *            OUTPUT - SUBSONIC SOLUTION                  *
C     *                                                        *
C     **********************************************************
C
C
      DO 106 L=1,2
      IF(L.EQ.1) WRITE(3,302)
      IF(L.EQ.2) WRITE(3,303)
      WRITE(3,304)FLOW(L)
      WRITE(3,310)TITLE(INDVAR)
      WRITE(3,308)(K,Y(K),PS1PP1(K,L),PS1PP0(K,L),PS0PP0(K,L),
     -WSWP(K,L),PM3PP0(K,L,1),MM3(K,L,1),K=1,I)
      WRITE(3,311)TITLE(INDVAR)
      WRITE(3,309)(K,Y(K),PP1PS1(K,L),PP0PS1(K,L),PP0PS0(K,L),
     -WPWS(K,L),PM3PS0(K,L,1),PM3PS1(K,L,1),MM3(K,L,1),K=1,I)
C
C
C     **********************************************************
C     *                                                        *
C     *           OUTPUT - SUPERSONIC SOLUTION                 *
C     *                                                        *
C     **********************************************************
C
C
      WRITE(3,305)FLOW(L)
      WRITE(3,310)TITLE(INDVAR)
      WRITE(3,308)(K,Y(K),PS1PP1(K,L),PS1PP0(K,L),PS0PP0(K,L),
     -WSWP(K,L),PM3PP0(K,L,2),MM3(K,L,2),K=1,I)
      WRITE(3,311)TITLE(INDVAR)
      WRITE(3,309)(K,Y(K),PP1PS1(K,L),PP0PS1(K,L),PP0PS0(K,L),
     -WPWS(K,L),PM3PS0(K,L,2),PM3PS1(K,L,2),MM3(K,L,2),K=1,I)
C
C
C     **********************************************************
C     *                                                        *
```

7.3.1 CASSEP (Cont.)

```
C      *  OUTPUT - SUPERSONIC SOLUTION AT RD OF NORMAL SHOCK        *        CASSEP 20100
C      *   CONDITIONS                                                *        CASSEP 20200
C      *                                                             *        CASSEP 20300
C      ***************************************************************        CASSEP 20400
C                                                                             CASSEP 20500
C                                                                             CASSEP 20600
       WRITE(3,306)FLOW(L)                                                    CASSEP 20700
       WRITE(3,310)TITLE(INDVAR)                                              CASSEP 20800
       WRITE(3,308)(K,Y(K),PS1PP1(K,L),PS1PPO(K,L),PSOPPO(K,L),               CASSEP 20900
      -WSWP(K,L),PM3PPO(K,L,3),MM3(K,L,3),K=1,I)                              CASSEP 21000
       WRITE(3,311)TITLE(INDVAR)                                              CASSEP 21100
       WRITE(3,309)(K,Y(K),PP1PS1(K,L),PPOPS1(K,L),PPOPSO(K,L),               CASSEP 21200
      -WPWS(K,L),PM3PSO(K,L,3),PM3PS1(K,L,3),MM3(K,L,3),K=1,I)                CASSEP 21300
C                                                                             CASSEP 21400
C                                                                             CASSEP 21500
C      ***************************************************************        CASSEP 21600
C      *                                                             *        CASSEP 21700
C      *                  OUTPUT - MIXED PROPERTIES                  *        CASSEP 21800
C      *                                                             *        CASSEP 21900
C      ***************************************************************        CASSEP 22000
C                                                                             CASSEP 22100
C                                                                             CASSEP 22200
       WRITE(3,307)FLOW(L)                                                    CASSEP 22300
       WRITE(3,312)TITLE(INDVAR)                                              CASSEP 22400
       WRITE(3,309)(K,Y(K),PS1PP1(K,L),PS1PPO(K,L),PSOPPO(K,L),               CASSEP 22500
      -WSWP(K,L),MWMMWP(K,L),TMOTPO(K,L),GM( ,L),K=1,I)                       CASSEP 22600
       WRITE(3,313)TITLE(INDVAR)                                              CASSEP 22700
106    WRITE(3,309)(K,Y(K),PP1PS1(K,L),PPOPS1(K,L),PPOPSO(K,L),               CASSEP 22800
      -WPWS(K,L),MWMMWS(K,L),TMOTSO(K,L),GM(K,L),K=1,I)                       CASSEP 22900
       STOP                                                                   CASSEP 23000
C                                                                             CASSEP 23100
C                                                                             CASSEP 23200
C      ***************************************************************        CASSEP 23300
C      *                                                             *        CASSEP 23400
C      *                     FAILURE INDICATORS                      *        CASSEP 23500
C      *                                                             *        CASSEP 23600
C      ***************************************************************        CASSEP 23700
C                                                                             CASSEP 23800
C                                                                             CASSEP 23900
107    WRITE(5,400)(CATALG(K),K=1,8)                                          CASSEP 24000
       GO TO 100                                                              CASSEP 24100
108    WRITE(5,401)VARBLE,Y(I)                                                CASSEP 24200
       STOP                                                                   CASSEP 24300
109    WRITE(5,402)I,VARBLE                                                   CASSEP 24400
       STOP                                                                   CASSEP 24500
C                                                                             CASSEP 24600
C                                                                             CASSEP 24700
C      ***************************************************************        CASSEP 24800
C      *                                                             *        CASSEP 24900
C      *                     FORMAT STATEMENTS                       *        CASSEP 25000
```

7.3.1 CASSEP (Cont.)

```
C      *                                                            *
C      **************************************************************
C
C
200    FORMAT('0',T2,'INPUT INDEPENDENT VARIABLE - TYPE "H" FOR',
      -' HELP')
201    FORMAT(A6)
202    FORMAT('0',T2,'INPUT ',7(A6,', '),'ERRCR')
203    FORMAT(7F,D)
204    FORMAT('0',T2,'INPUT LOW VALUE, INCREMENT, AND HIGH ',
      -'VALUE OF ',A6)
205    FORMAT(3F)
C
300    FORMAT('1',T44,'CONSTANT-AREA SUPERSONIC-SUPERSONIC ',
      -'EJECTOR',/,T58,'PARAMETRIC DATA',/,T54,'ONE-DIMENSIONAL',
      -' ANALYSIS',//,T59,'C.D. MIKKELSEN',/,T62,'1 MAY 75',//,
      -T49,'MECHANICAL ENGINEERING DEPARTMENT',/,T45,
      -'UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN',/,T55,
      -'URBANA, ILLINOIS 61801')
301    FORMAT('0',3(T44,A6,T51,'=',D13.6,T67,A6,T74,'=',D13.6,/),
      -T44,A6,T51,'=',D13.6,T67,'ERROR',T74,'=',D13.6)
302    FORMAT('-',T45,'BO INDICATES THE UPPER LIMIT OF THE ',
      -'PLANE',/,T49,'OF SUPERSONIC-SUPERSONIC OPERATION')
303    FORMAT('1',T45,'MP INDICATES THE LOWER LIMIT OF THE ',
      -'PLANE',/,T49,'OF SUPERSONIC-SUPERSONIC OPERATION')
304    FORMAT('-',T53,A6,'SUBSONIC SOLUTIONS')
305    FORMAT('1',T51,A6,'SUPERSONIC SOLUTIONS')
306    FORMAT('1',T35,A6,'SUPERSONIC SOLUTIONS AT RD OF NORMAL',
      -' SHOCK CONDITIONS')
307    FORMAT('1',T54,A6,'MIXED PROPERTIES')
308    FORMAT(' ',T9,I2,6D14.6,T109,D14.6)
309    FORMAT(' ',T9,I2,8D14.6)
310    FORMAT('0',T9,'NC',T16,A6,T30,'PS1PP1',T44,'PS1PP0',T58,
      -'PSCPP0',T73,'WSWP',T86,'PM3PP0',T116,'MM3',/)
311    FORMAT('0',T9,'NC',T16,A6,T30,'PP1PS1',T44,'PP0PS1',T58,
      -'PP0PS0',T73,'WPWS',T86,'PM3PS0',T100,'PM3PS1',T116,'MM3',
      -/)
312    FORMAT('0',T9,'NO',T16,A6,T30,'PS1PP1',T44,'PS1PP0',T58,
      -'PS0PP0',T73,'WSWP',T86,'MWMMWP',T100,'TMOTP0',T116,'GM',
      -/)
313    FORMAT('0',T9,'NO',T16,A6,T30,'PP1PS1',T44,'PP0PS1',T58,
      -'PP0PS0',T73,'WPWS',T86,'MWMMWS',T100,'TMOTS0',T116,'GM',
      -/)
C
400    FORMAT('0',T2,'SELECT THE INDEPENDENT VARIABLE FROM THE ',
      -'FOLLOWING',/,T2,'CATALOG OF EJECTOR PARAMETERS:',//,T2,
      -7(A6,', '),A6)
401    FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE CASSE ',
      -'FOR ',A6,'=',D13.6)
402    FORMAT('0',T2,I3,' VALUE OF ',A6,' EXCEEDS THE PROGRAM ',
```

7.3.1 CASSEP (Cont.)

```
-'DIMENSIONS')                                                     CASSEP 30100
 END                                                               CASSEP 30200
```

7.3.1 CASSEP (Cont.)

```
C     ************************************************************    CASSE  00100
C     *                                                          *    CASSE  00200
C     *           CONSTANT-AREA SUPERSONIC-SUPERSONIC            *    CASSE  00300
C     *                EJECTOR SUBROUTINE (CASSE)                *    CASSE  00400
C     *                                                          *    CASSE  00500
C     ************************************************************    CASSE  00600
C                                                                     CASSE  00700
C     ************************************************************    CASSE  00800
C     *                                                          *    CASSE  00900
C     *  CASSE IS A SUBROUTINE FOR CALCULATING THE PLANE OF      *    CASSE  01000
C     *  OPERATION OF A CONSTANT-AREA SUPERSONIC-SUPERSONIC      *    CASSE  01100
C     *  EJECTOR BY ONE-DIMENSIONAL ANALYSIS.                    *    CASSE  01200
C     *                                                          *    CASSE  01300
C     *  INPUT DATA:                                             *    CASSE  01400
C     *                                                          *    CASSE  01500
C     *  GS     = SECONDARY GAMMA                                *    CASSE  01600
C     *  GP     = PRIMARY GAMMA                                  *    CASSE  01700
C     *  MWSMWP = SECONDARY-TO-PRIMARY MOLECULAR WEIGHT RATIO    *    CASSE  01800
C     *  TSOTPO = SECONDARY-TO-PRIMARY STAGNATION TEMPERATURE    *    CASSE  01900
C     *           RATIO                                          *    CASSE  02000
C     *  MS1    = SECONDARY MACH NO. AT STATION 1                *    CASSE  02100
C     *  MP1    = PRIMARY MACH NO. AT STATION 1                  *    CASSE  02200
C     *  AS1AP1 = SECONDARY-TO-PRIMARY AREA RATIO AT STATION 1   *    CASSE  02300
C     *  RD     = NORMAL SHOCK DIFFUSER COEFFICIENT              *    CASSE  02400
C     *  ERROR  = MAX PERCENT DEVIATION IN M(G,AAS)              *    CASSE  02500
C     *                                                          *    CASSE  02600
C     ************************************************************    CASSE  02700
C                                                                     CASSE  02800
C     ************************************************************    CASSE  02900
C     *                                                          *    CASSE  03000
C     *                    NOTATION SCHEME                       *    CASSE  03100
C     *                                                          *    CASSE  03200
C     *  VARIABLES ARE DEFINED AS FOLLOWS:                       *    CASSE  03300
C     *                                                          *    CASSE  03400
C     *  A : AREA                                                *    CASSE  03500
C     *  G : (GAMMA) SPECFIC HEAT RATIO                          *    CASSE  03600
C     *  M : MACH NUMBER                                         *    CASSE  03700
C     *  MW: MOLECULAR WEIGHT RATIO                              *    CASSE  03800
C     *  P : PRESSURE                                            *    CASSE  03900
C     *  T : TEMPERATURE                                         *    CASSE  04000
C     *  W : MASS FLOW RATE                                      *    CASSE  04100
C     *                                                          *    CASSE  04200
C     *  REPEATED LETTERS INDICATE RATIOS.                       *    CASSE  04300
C     *  EXAMPLE: AS1AP1=AS1/AP1                                 *    CASSE  04400
C     *                                                          *    CASSE  04500
C     *  S: INDICATES SECONDARY OR DRIVEN STREAM PROPERTIES      *    CASSE  04600
C     *  P: INDICATES PRIMARY OR DRIVING STREAM PROPERTIES       *    CASSE  04700
C     *  M: INDICATES MIXED STREAM PROPERTIES                    *    CASSE  04800
C     *  EXAMPLE: GM=MIXED STREAM SPECIFIC HEAT RATIO            *    CASSE  04900
C     *                                                          *    CASSE  05000
```

7.3.1 CASSEP (Cont.)

```
C      *  VARIABLES ARE DESIGNATED AS TO LOCATION AS FOLLOWS:      *      CASSE  05100
C      *                                                           *      CASSE  05200
C      *  1: MIXING TUBE ENTRANCE, THE CONFLUENCE POINT OF THE     *      CASSE  05300
C      *     SECCNDARY AND PRIMARY STREAMS                         *      CASSE  05400
C      *  2: POINT IN THE MIXING TUBE AT WHICH THE SECONDARY       *      CASSE  05500
C      *     STREAM IS RECOMPRESSED TO SONIC CONDITIONS            *      CASSE  05600
C      *  3: MIXING TUBE EXIT                                      *      CASSE  05700
C      *  EXAMPLE: PS1PP1=SECCNDARY-TO-PRIMARY STATIC PRESSURE     *      CASSE  05800
C      *           RATIC AT STATION 1                              *      CASSE  05900
C      *                                                           *      CASSE  06000
C      *  0: INDICATES STAGNATICN CONDITIONS                       *      CASSE  06100
C      *  EXAMPLE: TMOTPO=MIXED-TO-PRIMARY STAGNATION              *      CASSE  06200
C      *           TEMPERATURE RATIO                               *      CASSE  06300
C      *                                                           *      CASSE  06400
C      *  S: INDICATES "*" CONDITIONS                              *      CASSE  06500
C      *  EXAMPLE: AP1AFS=AF1/AP*                                  *      CASSE  06600
C      *                                                           *      CASSE  06700
C      *  VARIABLES NCT FOLLOWING THIS SCHEME ARE DEFINED AS       *      CASSE  06800
C      *  REQUIRED.                                                *      CASSE  06900
C      *                                                           *      CASSE  07000
C      *************************************************************      CASSE  07100
C                                                                         CASSE  07200
C                                                                         CASSE  07300
       SUBRCUTINE CASSE                                                   CASSE  07400
C                                                                         CASSE  07500
       IMPLICIT REAL*8(A-H,M,C-Z)                                         CASSE  07600
C                                                                         CASSE  07700
       COMMON/BLOCK1/MM3(51,2,3),PM3PPO(51,2,3),PM3PSO(51,2,3),           CASSE  07800
      -PM3PS1(51,2,3)                                                     CASSE  07900
       CCMMCN/BLCCK2/GM(51,2),MWMMWP(51,2),MWMMWS(51,2),                  CASSE  08000
      -PSOPPO(51,2),PS1PPO(51,2),PS1PP1(51,2),PPOPSO(51,2),               CASSE  08100
      -PPOPS1(51,2),PF1PS1(51,2),TMOTPO(51,2),TMOTSO(51,2),               CASSE  08200
      -WPWS(51,2),WSWP(51,2)                                              CASSE  08300
       COMMCN/BLCCK3/GS,GP,MWSMWP,TSOTPO,MS1,MP1,AS1AP1,RD,ERROR,         CASSE  08400
      -FAIL,I                                                             CASSE  08500
C                                                                         CASSE  08600
       CATA YES/'YES   '/                                                 CASSE  08700
C                                                                         CASSE  08800
C                                                                         CASSE  08900
C      *************************************************************      CASSE  09000
C      *                                                           *      CASSE  09100
C      *                    SPECIAL FUNCTIONS                      *      CASSE  09200
C      *                                                           *      CASSE  09300
C      *************************************************************      CASSE  09400
C                                                                         CASSE  09500
C                                                                         CASSE  09600
       F(GX,MXX)=1.0+GX*MXX*MXX                                           CASSE  09700
       G(GX,MXX)=MXX*DSQRT(1.0+0.5*(GX-1.0)*MXX*MXX)                      CASSE  09800
       H(MM,TT,GG)=DSQRT(MM*GG/TT)                                        CASSE  09900
       MDMU(GX,MXX)=DSQRT((MXX*MXX+2.0/(GX-1.0))/(2.0*GX*MXX*MXX          CASSE  10000
```

7.3.1 CASSEP (Cont.)

```
     -/(GX-1.0)-1.0))                                                   CASSE  10100
      PDPUMU(GX,MXX)=(2.C*GX*MXX*MXX-GX+1.0)/(GX+1.0)                   CASSE  10200
      PPOM(GX,MXX)=(1.0+0.5*(GX-1.0)*MXX*MXX)**(GX/(1.0-GX))            CASSE  10300
      AASM(GX,MXX)=((2.0*(1.0+0.5*(GX-1.0)*MXX*MXX)/(GX+1.0))**         CASSE  10400
     -(0.5*(GX+1.0)/(GX-1.0)))/MXX                                      CASSE  10500
C                                                                       CASSE  10600
C                                                                       CASSE  10700
C     ***************************************************************   CASSE  10800
C     *                                                             *   CASSE  10900
C     *              CHECK CONSISTENCY OF INPUT DATA                *   CASSE  11000
C     *                                                             *   CASSE  11100
C     ***************************************************************   CASSE  11200
C                                                                       CASSE  11300
C                                                                       CASSE  11400
      IF(MS1.LE.1.0) GC TO 104                                          CASSE  11500
      IF(MP1.LE.1.0) GO TO 105                                          CASSE  11600
C                                                                       CASSE  11700
C                                                                       CASSE  11800
C     ***************************************************************   CASSE  11900
C     *                                                             *   CASSE  12000
C     *                   CALCULATE CONSTANTS                       *   CASSE  12100
C     *                                                             *   CASSE  12200
C     ***************************************************************   CASSE  12300
C                                                                       CASSE  12400
C                                                                       CASSE  12500
      GP1=(GP-1.C)/2.0                                                  CASSE  12600
      GP1I=1.0/GP1                                                      CASSE  12700
      GP2=2.0/(GP+1.C)                                                  CASSE  12800
      GP2I=1.0/GP2                                                      CASSE  12900
      GS3=GS/(GS-1.0)                                                   CASSE  13000
      GP3=GP/(GP-1.0)                                                   CASSE  13100
      GP4=(GP+1.0)/(2.C*(GP-1.0))                                       CASSE  13200
      GP4I=1.0/GP4                                                      CASSE  13300
      GSGP=GS/GP                                                        CASSE  13400
      MWPMWS=1.0/MWSMWP                                                 CASSE  13500
      PS1PS0=PPCM(GS,MS1)                                               CASSE  13600
      PP1PP0=PPOM(GP,MP1)                                               CASSE  13700
      AS1ASS=AASM(GS,MS1)                                               CASSE  13800
      AP1APS=AASM(GP,MP1)                                               CASSE  13900
      ASSAS1=1.C/AS1ASS                                                 CASSE  14000
      FGSMS1=F(GS,MS1)                                                  CASSE  14100
      FGPMP1=F(GP,MP1)                                                  CASSE  14200
      GGSMS1=G(GS,MS1)                                                  CASSE  14300
      GGPMP1=G(GP,MP1)                                                  CASSE  14400
C                                                                       CASSE  14500
C                                                                       CASSE  14600
C     ***************************************************************   CASSE  14700
C     *                                                             *   CASSE  14800
C     *  CALCULATE PS1PP1(I,1) FOR AN ISENTROPIC RECOMPRESSION      *   CASSE  14900
C     *  OF THE SECONDARY STREAM TO SONIC CONDITIONS AT             *   CASSE  15000
```

7.3.1 CASSEP (Cont.)

```
C     *  STATION 2.  MP2 IS OBTAINED FROM AP2AP2 BY LINEAR          *
C     *  ITERATION.                                                 *
C     *                                                             *
C     ***************************************************************
C
C
      AP2APS=AP1APS*(1.0+AS1AP1*(1.0-ASSAS1))
      MP2=MP1
      DO 100 J=1,200
      C1=(MP2*AP2APS)**GP4I
      XMP2=DSQRT(GP1I*(GP2I*C1-1.0))
      XERROR=(XMP2-MP2)*100.0/MP2
      MP2=XMP2
      IF(DABS(XERROR).LT.ERROR) GO TO 101
100   CONTINUE
      GO TO 106
101   MS2=1.0
      C1=-FGPMP1+F(GP,MP2)*GGPMP1/G(GP,MP2)
      C2=FGSMS1-F(GS,MS2)*GGSMS1/G(GS,MS2)
      PS1PP1(I,1)=C1/(AS1AP1*C2)
C
C
C     ***************************************************************
C     *                                                             *
C     *    SET FS1PP1(I,2) FOR MATCHED PRESSURE CONDITIONS.         *
C     *                                                             *
C     ***************************************************************
C
C
      PS1PP1(I,2)=1.0
C
C
C     ***************************************************************
C     *                                                             *
C     *             OVERALL CONTROL VOLUME CALCULATIONS             *
C     *                                                             *
C     ***************************************************************
C
C
      DO 103 L=1,2
      WSWP(I,L)=PS1PP1(I,L)*AS1AP1*H(MWSMWP,TSOTPO,GSGP)*GGSMS1
     -/GGPMP1
      WPWS(I,L)=1.0/WSWP(I,L)
      C1=WSWP(I,L)*MWPMWS*GS3+GP3
      C2=WSWP(I,L)*MWPMWS*(GS3-1.0)+(GP3-1.0)
      GM(I,L)=C1/C2
      GMGP=GM(I,L)/GP
      MWMMWP(I,L)=(WSWP(I,L)+1.0)/(WSWP(I,L)*MWPMWS+1.0)
      MWMMWS(I,L)=MWMMWP(I,L)*MWPMWS
      C1=TSOTPO*WSWP(I,L)*MWPMWS*GS3+GP3
```

7.3.1 CASSEP (Cont.)

```
      C2=WSWP(I,L)*MWPMWS*GS3+GP3                                      CASSE  20100
      TMOTPO(I,L)=C1/C2                                                CASSE  20200
      TMOTSO(I,L)=TMOTPO(I,L)/TSOTPO                                   CASSE  20300
      FFX=H(MWMMWP(I,L),TMOTPO(I,L),GMGP)*(PS1PP1(I,L)*AS1AP1          CASSE  20400
     -*FGSMS1+FGPMP1)/((1.0+WSWP(I,L))*GGPMP1)                         CASSE  20500
      C1=0.5*(GM(I,L)-1.0)*FFX*FFX-GM(I,L)*GM(I,L)                     CASSE  20600
      C2=FFX*FFX-2.0*GM(I,L)                                           CASSE  20700
      C3=(-C2+DSQRT(C2*C2+4.0*C1))/(2.0*C1)                            CASSE  20800
      C4=(-C2-DSQRT(C2*C2+4.0*C1))/(2.0*C1)                            CASSE  20900
C                                                                      CASSE  21000
C                                                                      CASSE  21100
C     ***********************************************************      CASSE  21200
C     *                                                         *      CASSE  21300
C     *      IDENTIFY THE SUPERSONIC AND SUBSONIC SOLUTIONS     *      CASSE  21400
C     *                                                         *      CASSE  21500
C     ***********************************************************      CASSE  21600
C                                                                      CASSE  21700
C                                                                      CASSE  21800
      MM3(I,L,1)=DSQRT(DMIN1(C3,C4))                                   CASSE  21900
      MM3(I,L,2)=DSQRT(DMAX1(C3,C4))                                   CASSE  22000
      DO 102 J=1,2                                                     CASSE  22100
      PM3PP1=(PS1PP1(I,L)*AS1AP1*FGSMS1+FGPMP1)/((1.0+AS1AP1)          CASSE  22200
     -*F(GM(I,L),MM3(I,L,J)))                                          CASSE  22300
      PM3PS1(I,L,J)=PM3PP1/PS1PP1(I,L)                                 CASSE  22400
      PM3PS0(I,L,J)=PM3PP1*PS1PS0/PS1PP1(I,L)                          CASSE  22500
102   PM3PP0(I,L,J)=PM3PP1*PP1PP0                                      CASSE  22600
      PP1PS1(I,L)=1.0/PS1PP1(I,L)                                      CASSE  22700
      PS1PP0(I,L)=PS1PP1(I,L)*PP1PP0                                   CASSE  22800
      PP0PS1(I,L)=1.0/PS1PP0(I,L)                                      CASSE  22900
      PS0PP0(I,L)=PS1PP1(I,L)*PP1PP0/PS1PS0                            CASSE  23000
      PP0PS0(I,L)=1.0/PS0PP0(I,L)                                      CASSE  23100
C                                                                      CASSE  23200
C                                                                      CASSE  23300
C     ***********************************************************      CASSE  23400
C     *                                                         *      CASSE  23500
C     *  DIFFUSE THE SUPERSONIC SOLUTION TO RD OF NORMAL SHOCK  *      CASSE  23600
C     *  CONDITIONS                                             *      CASSE  23700
C     *                                                         *      CASSE  23800
C     ***********************************************************      CASSE  23900
C                                                                      CASSE  24000
C                                                                      CASSE  24100
      C1=RD*PDPUMU(GM(I,L),MM3(I,L,2))                                 CASSE  24200
      PM3PS1(I,L,3)=C1*PM3PS1(I,L,2)                                   CASSE  24300
      PM3PS0(I,L,3)=C1*PM3PS0(I,L,2)                                   CASSE  24400
      PM3PP0(I,L,3)=C1*PM3PP0(I,L,2)                                   CASSE  24500
103   MM3(I,L,3)=MDMU(GM(I,L),MM3(I,L,2))                              CASSE  24600
      RETURN                                                           CASSE  24700
C                                                                      CASSE  24800
C                                                                      CASSE  24900
C     ***********************************************************      CASSE  25000
```

7.3.1 CASSEP (Cont.)

```
C      *
C      *                        FAILURE INDICATORS                          *
C      *                                                                    *
C      **********************************************************************
C
C
104    WRITE(5,200)MS1
       GO TO 107
105    WRITE(5,201)MP1
       GO TO 107
106    WRITE(5,202)MP2,XERROR,ERROR
107    FAIL=YES
       RETURN
C
C
C      **********************************************************************
C      *                                                                    *
C      *                        FORMAT STATEMENTS                           *
C      *                                                                    *
C      **********************************************************************
C
C
200    FORMAT('0','INPUT ERROR: MS1 =',E13.6,2X,'MS1 MUST BE ',
      -'SUPERSONIC')
201    FORMAT('0','INPUT ERROR: MP1 =',E13.6,2X,'MP1 MUST BE ',
      -'SUPERSONIC')
202    FORMAT('0',T2,'CONVERGENCE FAILURE',/,T2,'MP2 =',E13.6,2X,
      -'XERROR =',E13.6,2X,'ERROR =',E13.6)
       END
```

7.3.2 CASSEP Sample Input

```
INPUT INDEPENDENT VARIABLE - TYPE "H" FOR HELP
H

SELECT THE INDEPENDENT VARIABLE FROM THE FOLLOWING
CATALOG OF EJECTOR PARAMETERS:

GS    ,GP    ,MWSMWP,TS0TP0,MS1   ,MP1   ,AS1AP1,RD

INPUT INDEPENDENT VARIABLE - TYPE "H" FOR HELP
AS1AP1

INPUT GS    ,GP    ,MWSMWP,TS0TP0,MS1   ,MP1   ,RD    ,
ERROR
1.562, 1.34, 0.593912, 1.31341, 2.18, 4.690, 0.75, 5.0E-06

INPUT LOW VALUE, INCREMENT, AND HIGH VALUE OF AS1AP1
1.0, 1.0, 10.0
```

7.3.3 CASSEP Sample Output

CONSTANT-AREA SUPERSONIC-SUPERSONIC EJECTOR
PARAMETRIC DATA
ONE-DIMENSIONAL ANALYSIS

C.D. MIKKELSEN
1 MAY 75

MECHANICAL ENGINEERING DEPARTMENT
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
URBANA, ILLINOIS 61801

GS	=	0.156200D+01	GP	=	0.134000D+01
MWSMWP	=	0.593912D+00	TSOTPO	=	0.131341D+01
MS1	=	0.218000D+01	MP1	=	0.469000D+01
RD	=	0.750000D+00	ERROR	=	0.500000D-05

UL INDICATES THE UPPER LIMIT OF THE PLANE
OF SUPERSONIC-SUPERSONIC OPERATION

UL SUBSONIC SOLUTIONS

NO	AS1AP1	PS1PPO	PSOPPO	WSWP	PM3PPO	MM3
1	0.100000D+01	0.843536D-03	0.891096D-02	0.919989D-01	0.296420D-01	0.417080D+00
2	0.200000D+01	0.692846D-03	0.731910D-02	0.151126D+00	0.208017D-01	0.425312D+00
3	0.300000D+01	0.591519D-03	0.624870D-02	0.193539D+00	0.161594D-01	0.430679D+00
4	0.400000D+01	0.518105D-03	0.547316D-02	0.226025D+00	0.132689D-01	0.434522D+00
5	0.500000D+01	0.462163D-03	0.488220D-02	0.252025D+00	0.112848D-01	0.437445D+00
6	0.600000D+01	0.417952D-03	0.441517D-02	0.273499D+00	0.983354D-02	0.439764D+00
7	0.700000D+01	0.382032D-03	0.403572D-02	0.291660D+00	0.872327D-02	0.441662D+00
8	0.800000D+01	0.352208D-03	0.372067D-02	0.307304D+00	0.784502D-02	0.443252D+00
9	0.900000D+01	0.327008D-03	0.345445D-02	0.320981D+00	0.713209D-02	0.444610D+00
10	0.100000D+02	0.305405D-03	0.322624D-02	0.333085D+00	0.654126D-02	0.445787D+00

NO	AS1AP1	PPOPS1	PPOPSO	WPWS	PM3PSO	PM3PS1	MM3
1	0.100000D+01	0.118549D+04	0.112221D+03	0.108697D+02	0.332646D+01	0.351402D+02	0.417080D+00
2	0.200000D+01	0.144332D+04	0.136629D+03	0.661689D+01	0.284211D+01	0.300235D+02	0.425312D+00
3	0.300000D+01	0.169056D+04	0.160033D+03	0.516691D+01	0.258604D+01	0.273185D+02	0.430679D+00
4	0.400000D+01	0.193011D+04	0.182710D+03	0.442429D+01	0.242436D+01	0.256105D+02	0.434522D+00
5	0.500000D+01	0.216374D+04	0.204826D+03	0.396786D+01	0.231142D+01	0.244174D+02	0.437445D+00
6	0.600000D+01	0.239262D+04	0.226492D+03	0.365631D+01	0.222722D+01	0.235279D+02	0.439764D+00
7	0.700000D+01	0.261758D+04	0.247787D+03	0.342865D+01	0.216152D+01	0.228339D+02	0.441662D+00
8	0.800000D+01	0.283923D+04	0.268769D+03	0.325410D+01	0.210850D+01	0.222738D+02	0.443252D+00
9	0.900000D+01	0.305803D+04	0.289481D+03	0.311544D+01	0.206461D+01	0.218101D+02	0.444610D+00
10	0.100000D+02	0.327435D+04	0.309958D+03	0.300224D+01	0.202752D+01	0.214184D+02	0.445787D+00

7.?.3 CASSEP Sample Output (Cont.)

UL SUPERSONIC SOLUTIONS

NO	ASIAPI	PSIPPO	PSOPPO	WSWP	PM3PPO		MM3
1	0.100000D+01	0.843536D-03	0.891096D-02	0.919989D-01	0.142989D-02		0.425724D+01
2	0.200000D+01	0.692846D-03	0.731910D-02	0.151128D+00	0.110508D-02		0.405200D+01
3	0.300000D+01	0.591519D-03	0.624870D-02	0.193539D+00	0.911814D-03		0.392875D+01
4	0.400000D+[illegible]	[illegible]8105D-03	0.547316D-02	0.226025D+00	0.780853D-03		0.384505D+01
5	0.500000D+[illegible]	[illegible]163D-03	0.488220D-02	0.252025D+00	0.685249D-03		0.378377D+01
6	0.600000[illegible]	[illegible]7952D-03	0.441517D-02	0.273499D+00	0.611945D-03		0.373653D+01
7	0.700000D+[illegible]	[illegible]82032D-03	0.403572D-02	0.291660D+00	0.553727D-03		0.369875D+01
8	0.800000D+01	[illegible]352208D-03	0.372067D-02	0.307304D+00	0.506246D-03		0.366767D+01
9	0.900000D+01	0.327008D-03	0.345445D-02	0.320981D+00	0.466705D-03		0.364155D+01
10	0.100000D+02	0.305405D-03	0.322624D-02	0.333085D+00	0.433216D-03		0.361921D+01

NO	ASIAPI	PPCPS1	PPOPSO	WPWS	PM3PSO	PM3PS1	MM3
1	0.100000D+01	0.115549D+04	0.112221D+03	0.108697D+02	0.160465D+00	0.169512D+01	0.425724D+01
2	0.200000D+01	0.144332D+04	0.136629D+03	0.661689D+01	0.150985D+00	0.159498D+01	0.405200D+01
3	0.300000D+01	0.169056D+04	0.160033D+03	0.516691D+01	0.145921D+00	0.154148D+01	0.392875D+01
4	0.400000D+01	0.193011D+04	0.182710D+03	0.442429D+01	0.142669D+00	0.150713D+01	0.384505D+01
5	0.500000D+01	0.216374D+04	0.204826D+03	0.396786D+01	0.140357D+00	0.148270D+01	0.378377D+01
6	0.600000D+01	0.239262D+04	0.226492D+03	0.365631D+01	0.138601D+00	0.146415D+01	0.373653D+01
7	0.700000D+01	0.261758D+04	0.247787D+03	0.342865D+01	0.137207D+00	0.144943D+01	0.369875D+01
8	0.800000D+01	0.283923D+04	0.268769D+03	0.325410D+01	0.136063D+00	0.143735D+01	0.366767D+01
9	0.900000D+01	0.305803D+04	0.289481D+03	0.311544D+01	0.135102D+00	0.142720D+01	0.364155D+01
10	0.100000D+02	0.327435D+04	0.309958D+03	0.300224D+01	0.134279D+00	0.141850D+01	0.361921D+01

7.3.3 CASSEP Sample Output (Cont.)

UL SUPERSONIC SOLUTIONS AT RD OF NORMAL SHOCK CONDITIONS

NO	AS1AP1	PS1PP0	PS0PP0	WSWP	PM3PP0		MM3
1	0.100000D+01	0.843536D-03	0.891096D-02	0.919989D-01	0.222315D-01		0.417080D+00
2	0.200000D+01	0.692846D-03	0.731910D-02	0.151128D+00	0.156013D-01		0.425312D+00
3	0.300000D+01	0.591519D-03	0.624870D-02	0.193539D+00	0.121195D-01		0.430679D+00
4	0.400000D+01	0.518105D-03	0.547316D-02	0.226025D+00	0.995168D-02		0.434522D+00
5	0.500000D+01	0.462163D-03	0.488220D-02	0.252025D+00	0.846362D-02		0.437445D+00
6	0.600000D+01	0.417952D-03	0.441517D-02	0.273499D+00	0.737516D-02		0.439764D+00
7	0.700000D+01	0.382032D-03	0.403572D-02	0.291660D+00	0.654245D-02		0.441662D+00
8	0.800000D+01	0.352208D-03	0.372067D-02	0.307304D+00	0.588377D-02		0.443252D+00
9	0.900000D+01	0.327008D-03	0.345445D-02	0.320981D+00	0.534907D-02		0.444610D+00
10	0.100000D+02	0.305405D-03	0.322624D-02	0.333085D+00	0.490595D-02		0.445787D+00

NO	AS1AP1	PPCPS1	PPCPS0	WPWS	PM3PS0	PM3PS1	MM3
1	0.100000D+01	0.118549D+04	0.112221D+03	0.108697D+02	0.249485D+01	0.263551D+02	0.417080D+00
2	0.200000D+01	0.144332D+04	0.136629D+03	0.661689D+01	0.213158D+01	0.225177D+02	0.425312D+00
3	0.300000D+01	0.169056D+04	0.160033D+03	0.516691D+01	0.193953D+01	0.204889D+02	0.430679D+00
4	0.400000D+01	0.193011D+04	0.182710D+03	0.442429D+01	0.181827D+01	0.192079D+02	0.434522D+00
5	0.500000D+01	0.216374D+04	0.204826D+03	0.396786D+01	0.173357D+01	0.183131D+02	0.437445D+00
6	0.600000D+01	0.239262D+04	0.226492D+03	0.365631D+01	0.167041D+01	0.176460D+02	0.439764D+00
7	0.700000D+01	0.261758D+04	0.247787D+03	0.342865D+01	0.162114D+01	0.171254D+02	0.441662D+00
8	0.800000D+01	0.283923D+04	0.268769D+03	0.325410D+01	0.158137D+01	0.167054D+02	0.443252D+00
9	0.900000D+01	0.305803D+04	0.289481D+03	0.311544D+01	0.154845D+01	0.163576D+02	0.444610D+00
10	0.100000D+02	0.327435D+04	0.309958D+03	0.300224D+01	0.152064D+01	0.160638D+02	0.445787D+00

7.3.3 CASSEP Sample Output (Cont.)

UL MIXED PROPERTIES

NO	AS1AP1	PS1PP1	PS1PP0	WSWP	MWMMWP	TMOTPO	GM
1	0.100000D+01	0.388352D+00	0.843536D-03	0.919989D-01	0.945533D+00	0.103087D+01	0.135902D+01
2	0.200000D+01	0.318977D+00	0.692846D-03	0.151128D+00	0.917627D+00	0.104768D+01	0.136962D+01
3	0.300000D+01	0.272327D+00	0.591519D-03	0.193539D+00	0.900192D+00	0.105857D+01	0.137656D+01
4	0.400000D+01	0.238528D+00	0.518105D-03	0.226025D+00	0.888057D+00	0.106632D+01	0.138155D+01
5	0.500000D+01	0.212773D+00	0.462163D-03	0.252025D+00	0.879017D+00	0.107219D+01	0.138535D+01
6	0.600000D+01	0.192419D+00	0.417952D-03	0.273499D+00	0.871958D+00	0.107683D+01	0.138837D+01
7	0.700000D+01	0.175882D+00	0.382032D-03	0.291660D+00	0.866256D+00	0.108062D+01	0.139085D+01
8	0.800000D+01	0.162152D+00	0.352208D-03	0.307304D+00	0.861529D+00	0.108379D+01	0.139293D+01
9	0.900000D+01	0.150550D+00	0.327008D-03	0.320981D+00	0.857528D+00	0.108649D+01	0.139470D+01
10	0.100000D+02	0.140604D+00	0.305405D-03	0.333085D+00	0.854086D+00	0.108882D+01	0.139624D+01

NO	AS1AP1	PP1PS1	FPOPS1	WPWS	MWMMWS	TMOTSO	GM
1	0.100000D+01	0.257498D+01	0.116549D+04	0.108697D+02	0.159204D+01	0.784877D+00	0.135902D+01
2	0.200000D+01	0.313502D+01	0.144332D+04	0.661689D+01	0.154506D+01	0.797683D+00	0.136962D+01
3	0.300000D+01	0.367205D+01	0.169056D+04	0.516691D+01	0.151570D+01	0.805967D+00	0.137656D+01
4	0.400000D+01	0.419238D+01	0.193011D+04	0.442429D+01	0.149527D+01	0.811868D+00	0.138155D+01
5	0.500000D+01	0.469984D+01	0.216374D+04	0.396786D+01	0.148005D+01	0.816338D+00	0.138535D+01
6	0.600000D+01	0.519699D+01	0.239262D+04	0.365631D+01	0.146816D+01	0.819874D+00	0.138837D+01
7	0.700000D+01	0.568562D+01	0.261758D+04	0.342865D+01	0.145856D+01	0.822759D+00	0.139085D+01
8	0.800000D+01	0.616706D+01	0.283923D+04	0.325410D+01	0.145060D+01	0.825171D+00	0.139293D+01
9	0.900000D+01	0.664231D+01	0.305803D+04	0.311544D+01	0.144386D+01	0.827227D+00	0.139470D+01
0	0.100000D+02	0.711217D+01	0.327435D+04	0.300224D+01	0.143807D+01	0.829006D+00	0.139624D+01

7.3.3 CASSEP Sample Output (Cont.)

MP INDICATES THE LOWER LIMIT OF THE PLANE
OF SUPERSONIC-SUPERSONIC OPERATION

MP SUBSONIC SOLUTIONS

NO	AS1AP1	FS1PP0	PS0PP0	WSWP	PM3PP0	MM3
1	0.100000D+01	0.217209D-02	0.229456D-01	0.236895D+00	0.334576D-01	0.435760D+00
2	0.200000D+01	0.217209D-02	0.229456D-01	0.473791D+00	0.264320D-01	0.457993D+00
3	0.300000D+01	0.217209D-02	0.229456D-01	0.710686D+00	0.229005D-01	0.473865D+00
4	0.400000D+01	0.217209D-02	0.229456D-01	0.947582D+00	0.207722D-01	0.485795D+00
5	0.500000D+01	0.217209D-02	0.229456D-01	0.118448D+01	0.193481D-01	0.495102D+00
6	0.600000D+01	0.217209D-02	0.229456D-01	0.142137D+01	0.183276D-01	0.502574D+00
7	0.700000D+01	0.217209D-02	0.229456D-01	0.165827D+01	0.175602D-01	0.508708D+00
8	0.800000D+01	0.217209D-02	0.229456D-01	0.189516D+01	0.169620D-01	0.513836D+00
9	0.900000D+01	0.217209D-02	0.229456D-01	0.213206D+01	0.164824D-01	0.518189D+00
10	0.100000D+02	0.217209D-02	0.229456D-01	0.236895D+01	0.160894D-01	0.521931D+00

NO	AS1AP1	PP0PS1	PP0PS0	WPWS	PM3PS0	PM3PS1	MM3
1	0.100000D+01	0.460386D+03	0.435814D+02	0.422127D+01	0.145813D+01	0.154034D+02	0.435760D+00
2	0.200000D+01	0.460386D+03	0.435814D+02	0.211064D+01	0.115194D+01	0.121689D+02	0.457993D+00
3	0.300000D+01	0.460386D+03	0.435814D+02	0.140709D+01	0.998036D+00	0.105431D+02	0.473865D+00
4	0.400000D+01	0.460386D+03	0.435814D+02	0.105532D+01	0.905282D+00	0.956323D+01	0.485795D+00
5	0.500000D+01	0.460386D+03	0.435814D+02	0.844254D+00	0.843216D+00	0.890758D+01	0.495102D+00
6	0.600000D+01	0.460386D+03	0.435814D+02	0.703545D+00	0.798743D+00	0.843778D+01	0.502574D+00
7	0.700000D+01	0.460386D+03	0.435814D+02	0.603039D+00	0.765300D+00	0.808449D+01	0.508708D+00
8	0.800000D+01	0.460386D+03	0.435814D+02	0.527659D+00	0.739227D+00	0.780906D+01	0.513836D+00
9	0.900000D+01	0.460386D+03	0.435814D+02	0.469030D+00	0.718327D+00	0.758828D+01	0.518189D+00
10	0.100000D+02	0.460386D+03	0.435814D+02	0.422127D+00	0.701197D+00	0.749732D+01	0.521931D+00

7.3.3 CASSEP Sample Output (Cont.)

MP SUPERSONIC SOLUTIONS

NO	AS1AP1	PS1PP0	PS0PP0	WSWP	PM3PP0	MM3
1	0.100000D+01	0.217209D-02	0.229456D-01	0.236895D+00	0.199537D-02	0.381885D+01
2	0.200000D+01	0.217209D-02	0.229456D-01	0.473791D+00	0.197454D-02	0.340272D+01
3	0.300000D+01	0.217209D-02	0.229456D-01	0.710686D+00	0.198050D-02	0.315698D+01
4	0.400000D+01	0.217209D-02	0.229456D-01	0.947582D+00	0.199236D-02	0.299423D+01
5	0.500000D+01	0.217209D-02	0.229456D-01	0.118448D+01	0.200493D-02	0.287832D+01
6	0.600000D+01	0.217209D-02	0.229456D-01	0.142137D+01	0.201675D-02	0.279147D+01
7	0.700000D+01	0.217209D-02	0.229456D-01	0.165827D+01	0.202744D-02	0.272395D+01
8	0.800000D+01	0.217209D-02	0.229456D-01	0.189516D+01	0.203698D-02	0.266992D+01
9	0.900000D+01	0.217209D-02	0.229456D-01	0.213206D+01	0.204548D-02	0.262569D+01
10	0.100000D+02	0.217209D-02	0.229456D-01	0.236895D+01	0.205305D-02	0.258881D+01

NO	AS1AP1	PP0PS1	PP0PS0	WPWS	PM3PS0	PM3PS1	MM3
1	0.100000D+01	0.460386D+03	0.435814D+02	0.422127D+01	0.869612D-01	0.918642D+00	0.381885D+01
2	0.200000D+01	0.460386D+03	0.435814D+02	0.211064D+01	0.860531D-01	0.909049D+00	0.340272D+01
3	0.300000D+01	0.460386D+03	0.435814D+02	0.140709D+01	0.863130D-01	0.911795D+00	0.315698D+01
4	0.400000D+01	0.460386D+03	0.435814D+02	0.105532D+01	0.868300D-01	0.917256D+00	0.299423D+01
5	0.500000D+01	0.460386D+03	0.435814D+02	0.844254D+00	0.873778D-01	0.923044D+00	0.287832D+01
6	0.600000D+01	0.460386D+03	0.435814D+02	0.703545D+00	0.878927D-01	0.928483D+00	0.279147D+01
7	0.700000D+01	0.460386D+03	0.435814D+02	0.603039D+00	0.883585D-01	0.933403D+00	0.272395D+01
8	0.800000D+01	0.460386D+03	0.435814D+02	0.527659D+00	0.887745D-01	0.937798D+00	0.266992D+01
9	0.900000D+01	0.460386D+03	0.435814D+02	0.469030D+00	0.891448D-01	0.941710D+00	0.262569D+01
10	0.100000D+02	0.460386D+03	0.435814D+02	0.422127D+00	0.894749D-01	0.945197D+00	0.258881D+01

7.3.3 CASSEP Sample Output (Cont.)

MP SUPERSONIC SOLUTIONS AT RD OF NORMAL SHOCK CONDITIONS

NO	AS1AP1	PS1PP0	PS0PP0	WSWP	PM3PP0		MM3
1	0.100000D+01	0.217209D-02	0.229456D-01	0.236895D+00	0.250932D-01		0.435760D+00
2	0.200000D+01	0.217209D-02	0.229456D-01	0.473791D+00	0.198240D-01		0.457993D+00
3	0.300000D+01	0.217209D-02	0.229456D-01	0.710686D+00	0.171754D-01		0.473865D+00
4	0.400000D+01	0.217209D-02	0.229456D-01	0.947582D+00	0.155792D-01		0.485795D+00
5	0.500000D+01	0.217209D-02	0.229456D-01	0.118448D+01	0.145110D-01		0.495102D+00
6	0.600000D+01	0.217209D-02	0.229456D-01	0.142137D+01	0.137457D-01		0.502574D+00
7	0.700000D+01	0.217209D-02	0.229456D-01	0.165827D+01	0.131702D-01		0.508708D+00
8	0.800000D+01	0.217209D-02	0.229456D-01	0.189516D+01	0.127215D-01		0.513836D+00
9	0.900000D+01	0.217209D-02	0.229456D-01	0.213206D+01	0.123618D-01		0.518189D+00
10	0.100000D+02	0.217209D-02	0.229456D-01	0.236895D+01	0.120670D-01		0.521931D+00

NO	AS1AP1	PP0PS1	PF0PS0	WPWS	PM3PS0	PM3PS1	MM3
1	0.100000D+01	0.460386D+03	0.435814D+02	0.422127D+01	0.109360D+01	0.115526D+02	0.435760D+00
2	0.200000D+01	0.460386D+03	0.435814D+02	0.211064D+01	0.863957D+00	0.912668D+01	0.457993D+00
3	0.300000D+01	0.460386D+03	0.435814D+02	0.140709D+01	0.748527D+00	0.790730D+01	0.473865D+00
4	0.400000D+01	0.460386D+03	0.435814D+02	0.105532D+01	0.678961D+00	0.717243D+01	0.485795D+00
5	0.500000D+01	0.460386D+03	0.435814D+02	0.844254D+00	0.632412D+00	0.668069D+01	0.495102D+00
6	0.600000D+01	0.460386D+03	0.435814D+02	0.703545D+00	0.599058D+00	0.632834D+ 1	0.502574D+00
7	0.700000D+01	0.460386D+03	0.435814D+02	0.603039D+00	0.573975D+00	0.606336D+01	0.508708D+00
8	0.800000D+01	0.460386D+03	0.435814D+02	0.527659D+00	0.554420D+00	0.585680D+01	0.513836D+00
9	0.900000D+01	0.460386D+03	0.435814D+02	0.469030D+00	0.538745D+00	0.569121D+01	0.518189D+00
10	0.100000D+02	0.460386D+03	0.435814D+02	0.422127D+00	0.525898D+00	0.555549D+01	0.521931D+00

7.3.3 CASSEP Sample Output (Cont.)

MP MIXED PROPERTIES

NO	AS1AP1	PS1PP1	PS1PP0	WSWP	MWMMWP	TMOTP0	GM
1	0.100000D+01	0.100000D+01	0.217209D-02	0.236895D+00	0.884209D+00	0.106880D+01	0.138316D+01
2	0.200000D+01	0.100000D+01	0.217209D-02	0.473791D+00	0.819799D+00	0.111284D+01	0.141227D+01
3	0.300000D+01	0.100000D+01	0.217209D-02	0.710686D+00	0.778782D+00	0.114344D+01	0.143322D+01
4	0.400000D+01	0.100000D+01	0.217209D-02	0.947582D+00	0.750371D+00	0.116593D+01	0.144904D+01
5	0.500000D+01	0.100000D+01	0.217209D-02	0.118448D+01	0.729529D+00	0.118317D+01	0.146139D+01
6	0.600000D+01	0.100000D+01	0.217209D-02	0.142137D+01	0.713588D+00	0.119680D+01	0.147131D+01
7	0.700000D+01	0.100000D+01	0.217209D-02	0.165827D+01	0.701000D+00	0.120785D+01	0.147945D+01
8	0.800000D+01	0.100000D+01	0.217209D-02	0.189516D+01	0.690808D+00	0.121699D+01	0.148624D+01
9	0.900000D+01	0.100000D+01	0.217209D-02	0.213206D+01	0.682387D+00	0.122467D+01	0.149201D+01
10	0.100000D+02	0.100000D+01	0.217209D-02	0.236895D+01	0.675313D+00	0.123121D+01	0.149696D+01

NO	AS1AP1	PF1PS1	PP0PS1	WPWS	MWMMWS	TMOTS0	GM
1	0.100000D+01	0.100000D+01	0.460386D+03	0.422127D+01	0.148879D+01	0.813763D+00	0.138316D+01
2	0.200000D+01	0.100000D+01	0.460386D+03	0.211064D+01	0.138034D+01	0.847289D+00	0.141227D+01
3	0.300000D+01	0.100000D+01	0.460386D+03	0.140709D+01	0.131127D+01	0.870586D+00	0.143322D+01
4	0.400000D+01	0.100000D+01	0.460386D+03	0.105532D+01	0.126344D+01	0.887[illegible]5D+00	0.144904D+01
5	0.500000D+01	0.100000D+01	0.460386D+03	0.844254D+00	0.122835D+01	0.900840D+00	0.146139D+01
6	0.600000D+01	0.100000D+01	0.460386D+03	0.703545D+00	0.120150D+01	0.911218D+00	0.147131D+01
7	0.700000D+01	0.100000D+01	0.460386D+03	0.603039D+00	0.118031D+01	0.919629D+00	0.147945D+01
8	0.800000D+01	0.100000D+01	0.460386D+03	0.527659D+00	0.116315D+01	0.926585D+00	0.148624D+01
9	0.900000D+01	0.100000D+01	0.460386D+03	0.469030D+00	0.114897D+01	0.932432D+00	0.149201D+01
10	0.100000D+02	0.100000D+01	0.460386D+03	0.422127D+00	0.113706D+01	0.937417D+00	0.149696D+01

7.4 CHEMICAL LASER GAS DYNAMICS OPTIMIZATION COMPUTER PROGRAM

7.4.1 Computer Program

```
C     **********************************************************
C     *                                                        *
C     *    CHEMICAL LASER GAS DYNAMICS OPTIMIZATION PROGRAM    *
C     *                       (CLGDOP)                         *
C     *                                                        *
C     *             WRITTEN BY: A.L. ADDY                      *
C     *                         C.D. MIKKELSEN                 *
C     *                         M.R. SANDBERG                  *
C     *                                                        *
C     *                    1 JANUARY 76                        *
C     *                                                        *
C     *           MECHANICAL ENGINEERING DEPARTMENT            *
C     *       UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN       *
C     *               URBANA, ILLINOIS 61801                   *
C     *                                                        *
C     *   CLGDOP IS A PROGRAM FOR OPTIMIZING THE PRESSURE      *
C     *   RECOVERY SUBSYSTEM OF HIGH ENERGY CHEMICAL LASER     *
C     *   SYSTEMS BY ONE-DIMENSIONAL ANALYSIS.  THE OPTIMUM    *
C     *   IS TAKEN TO BE THAT CONFIGURATION WHICH REQUIRES     *
C     *   THE MINIMUM DRIVER MASS FLOW FOR A GIVEN DRIVER      *
C     *   STAGNATION PRESSURE (OR VICE VERSA) AND GIVEN        *
C     *   COMPRESSION RATIO. CLGDOP IS A FORTRAN IV PROGRAM    *
C     *   WRITTEN FOR DEC SYSTEM-10 (F40).                     *
C     *                                                        *
C     **********************************************************
C
C     **********************************************************
C     *                                                        *
C     *                  NOTATION SCHEME                       *
C     *                                                        *
C     *  VARIABLES ARE DEFINED AS FOLLOWS:                     *
C     *                                                        *
C     *  A : AREA                                              *
C     *  G : (GAMMA) SPECIFIC HEAT RATIO                       *
C     *  M : MACH NUMBER                                       *
C     *  MW: MOLECULAR WEIGHT                                  *
C     *  P : PRESSURE                                          *
C     *  T : TEMPERATURE                                       *
C     *  W : MASS FLOW RATE                                    *
C     *                                                        *
C     *  REPEATED LETTERS INDICATE RATIOS.                     *
C     *  EXAMPLE: A2A1=A2/A1                                   *
C     *                                                        *
C     *  VARIABLES ARE DESIGNATED AS TO LOCATION BY THE        *
C     *  FOLLOWING:                                            *
C     *                                                        *
C     *  POINT 1: LASER CAVITY ENTRANCE                        *
C     *  POINT 2: LASER CAVITY EXIT                            *
C     *  POINT 3: NORMAL SHOCK DIFFUSER EXIT                   *
C     *  POINT 4: SUBSONIC DIFFUSER EXIT                       *
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7.4.1 CLGDOP (Cont.)

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C      *  POINT 5: EJECTCR SECONDARY NOZZLE EXIT                        *        CLGDOP 05100
C      *  POINT 6: EJECTCR PRIMARY NOZZLE EXIT                          *        CLGDOP 05200
C      *  POINT 7: EJECTCR MIXING TUBE EXIT                             *        CLGDOP 05300
C      *  POINT 8: SUBSONIC DIFFUSER EXIT                               *        CLGDOP 05400
C      *  EXAMPLE: P8P2= SUBSONIC DIFFUSER EXIT-TO-LASER CAVITY        *        CLGDOP 05500
C      *           EXIT STATIC PRESSURE RATIO                          *        CLGDOP 05600
C      *                                                                *        CLGDOP 05700
C      *  S: INDICATES SECONDARY OR DRIVEN STREAM PROPERTIES            *        CLGDOP 05800
C      *  P: INDICATES PRIMARY OR DRIVING STREAM PROPERTIES             *        CLGDOP 05900
C      *  M: INDICATES MIXED STREAM PROPERTIES                          *        CLGDOP 06000
C      *  EXAMPLE: GM= MIXED STREAM SPECIFIC HEAT RATIO                 *        CLGDOP 06100
C      *                                                                *        CLGDOP 06200
C      *  0: INDICATES STAGNATICN CONDITIONS                            *        CLGDOP 06300
C      *  EXAMPLE: T20T10= LASER CAVITY EXIT-TO-ENTRANCE                *        CLGDOP 06400
C      *           STAGNATICN TEMPERATURE RATIO                         *        CLGDOP 06500
C      *                                                                *        CLGDOP 06600
C      *  VARIABLES NCT FOLLOWING THIS SCHEME ARE DEFINED               *        CLGDOP 06700
C      *  AS REQUIRED.                                                  *        CLGDOP 06800
C      *                                                                *        CLGDOP 06900
C      ******************************************************************        CLGDOP 07000
C                                                                                CLGDOP 07100
C                                                                                CLGDOP 07200
       IMPLICIT REAL*4 (M)                                                       CLGDOP 07300
       REAL*4 NO                                                                 CLGDOP 07400
C                                                                                CLGDOP 07500
       COMMON/TTY1/A2A1,A3A1,A4A1,A4A3,A5A1,A5A6,A6A1,A7A1,A7A2,                 CLGDOP 07600
      -A7A6,A8A1,A8A7                                                            CLGDOP 07700
       COMMON/TTY2/COEFF,CQ1,CQ2,EJECT,GM,GP,GS                                  CLGDOP 07800
       COMMCN/TTY3/M1,M2,M3,M4,M5,M6,M7,M8,MWMMWS,MWPMWS,NPTS                    CLGDOP 07900
       COMMON/TTY4/P1P10,P2P1,P20P10,P3P1,P30P10,P3P2,P30P20,                    CLGDOP 08000
      -P4P1,P40P10,P4P3,P40P30,P5P1,P50P10,XP60P1,P60P10,P60P2,                  CLGDOP 08100
      -P60P20,P60P50,P7P1,P70P10,P7P2,P70P20,P7P50,P70P50,XP8P1,                 CLGDOP 08200
      -P80P10,P8P2,P80P20,P8P7,P80P70                                            CLGDOP 08300
       COMMON/TTY5/RNSD,RSD34,RSD78                                              CLGDOP 08400
       COMMON/TTY6/T1T10,T2T1,T20T10,T3T1,T30T10,T3T2,T30T20,                    CLGDOP 08500
      -T4T1,T40T10,T4T3,T40T30,T5T1,T50T10,T60T1,T60T10,T60T20,                  CLGDOP 08600
      -T60T50,T7T1,T70T10,T7T2,T70T20,T7T50,T70T50,T8T1,                         CLGDOP 08700
      -T80T10,T8T2,T80T20,T8T7,T80T70                                            CLGDOP 08800
       COMMON/TTY7/WMWS,XWPWS                                                    CLGDOP 08900
C                                                                                CLGDOP 09000
       DATA P60P1C/'P60P1'/,WPWSC/'WPWS'/,CAE/'CAE'/,SSE/'SSE'/,                 CLGDOP 09100
      -YES/'YES'/,NO/'NO'/,PART/'PART'/                                          CLGDOP 09200
C                                                                                CLGDOP 09300
       DATA GS,M1,A2A1,CQ1,CQ2,NPTS/1.400,2.0,1.0,2*0.0,21/                      CLGDOP 09400
       DATA P8P1,P60P1,WPWS/76.0,2.5E+03,1.0/                                    CLGDOP 09500
       DATA RNSD,A4A3/2*1.0/                                                     CLGDOP 09600
       DATA GP,MWPMWS,T60T50,T60T20,A8A7/1.400,4*1.0/                            CLGDOP 09700
C                                                                                CLGDOP 09800
       NAMELIST/CAV/GS,M1,A2A1,CQ1,CQ2,NPTS                                      CLGDOP 09900
       NAMELIST/CONST1/P8P1,P60P1                                                CLGDOP 10000
```

```
      NAMELIST/CONST2/P8P1,WPWS
      NAMELIST/DIFUSR/RNSD,A4A3
      NAMELIST/EJECT1/GP,MWPMWS,T60T50,A8A7
      NAMELIST/EJECT2/GP,MWPMWS,T60T20,A8A7
C
      TOTM(GX,MX)=1.0+((GX-1.0)/2.0)*MX*MX
      POPM(GX,MX)=(1.0+((GX-1.0)/2.0)*MX*MX)**(GX/(GX-1.0))
      WM(GX,MX)=MX*SQRT(GX*(1.0+((GX-1.0)/2.0)*MX*MX))
C
C
C     **********************************************************
C     *                                                        *
C     *             SECTION I: LASER CAVITY ANALYSIS           *
C     *                                                        *
C     *    VARIABLES USED IN THIS SECTION AND THEIR DEFAULT    *
C     *    VALUES ARE:                                         *
C     *                                                        *
C     *    1. GS(1.400)  : RATIO OF SPECIFIC HEATS             *
C     *    2. M1(2.0)    : CAVITY ENTRANCE MACH NUMBER         *
C     *    3. A2A1(1.0)  : CAVITY EXIT-TO-ENTRANCE AREA RATIO  *
C     *    4. CQ1(0.0)   : HEAT ADDITION COEFFICIENT           *
C     *    5. CQ2(0.0)   : HEAT ADDITION COEFFICIENT           *
C     *    6. NPTS(21)   : CAVITY INTEGRATION INCREMENTS       *
C     *                                                        *
C     *    NOTES:                                              *
C     *    1. VALUES OF ALL INPUT VARIABLES MUST BE DEFINED    *
C     *       EITHER BY INPUT OR DEFAULT.                      *
C     *    2. ALL VARIABLE INPUT IS BY NAMELIST.               *
C     *    3. THE MAXIMUM NUMBER OF INTEGRATION STEPS IS 25.   *
C     *                                                        *
C     **********************************************************
C
C
100   WRITE(5,200)
      WRITE(5,CAV)
      READ(5,CAV)
      X1=0.0
      X2=1.0
      A1=1.0
      A2=A2A1
      FAIL=NO
C
C
C     **********************************************************
C     *                                                        *
C     *             CALCULATIONS FOR LASER CAVITY              *
C     *                                                        *
C     **********************************************************
C
C
```

```
      CALL CAVITY(GS,M1,X1,X2,A1,A2,CQ1,CQ2,NPTS,M2,T2T1,T20T10,
     -P2P1,P20P10,FAIL)
      T1T10=1.0/TOTM(GS,M1)
      P1P10=1.0/POPM(GS,M1)
      T20T2=TOTM(GS,M2)
      P20P2=POPM(GS,M2)
      IF(FAIL.EQ.YES) GO TO 119
C
C     ***********************************************************
C     *                                                         *
C     *               SECTION II: SYSTEM CONSTRAINTS            *
C     *                                                         *
C     *  ONE OF TWO VARIABLES MAY BE SELECTED FOR MINIMIZATION  *
C     *  WHILE THE ONE NOT CHOSEN BECOMES A SYSTEM CONSTRAINT.  *
C     *  THESE VARIABLES ARE:                                   *
C     *                                                         *
C     *  P60P1: PRIMARY STAGNATION-TO-LASER CAVITY ENTRANCE     *
C     *         STATIC PRESSURE RATIO                           *
C     *  WPWS : PRIMARY-TO-SECONDARY MASS FLOW RATIO            *
C     *                                                         *
C     *     VARIABLES USED IN THIS SECTION AND THEIR DEFAULT    *
C     *     VALUES ARE:                                         *
C     *                                                         *
C     *  1. P8P1(76.0)     : SUBSONIC DIFFUSER EXIT-TO-LASER    *
C     *                      CAVITY ENTRANCE STATIC PRESSURE    *
C     *                      RATIO                              *
C     *  2. P60P1(2.5E+03): PRIMARY STAGNATION-TO-LASER CAVITY  *
C     *                      ENTRANCE STATIC PRESSURE RATIO     *
C     *  3. WPWS(1.0)      : PRIMARY-TO-SECONDARY MASS FLOW     *
C     *                      RATIO                              *
C     *                                                         *
C     *     ALL VARIABLE INPUT IS BY NAMELIST.                  *
C     *                                                         *
C     ***********************************************************
C
C
      WRITE(5,201)
      READ(5,202)COEFF
      WRITE(5,203)
      IF(COEFF.EQ.P60P1C) GO TO 101
      WRITE(5,CONST1)
      READ(5,CONST1)
      GO TO 102
  101 WRITE(5,CONST2)
      READ(5,CONST2)
C
C
C     ***********************************************************
C     *                                                         *
```

7.4.1 CLGDOP (Cont.)

```
C      *                 SECTION II: EJECTOR ANALYSIS                        *
C      *                                                                     *
C      *     ONE OF TWO EJECTOR CONFIGURATIONS MAY BE CHOSEN                 *
C      *     TO REPRESSURIZE THE LASER CAVITY FLOW.  THESE                   *
C      *     CONFIGURATIONS ARE:                                             *
C      *                                                                     *
C      *     CAE: NORMAL SHOCK DIFFUSER - SUBSONIC DIFFUSER -                *
C      *          CONSTANT-AREA SUBSONIC-SUPERSONIC EJECTOR -                *
C      *          SUBSONIC DIFFUSER                                          *
C      *     SSE: CONSTANT-AREA SUPERSONIC-SUPERSONIC EJECTOR -              *
C      *          SUBSONIC DIFFUSER                                          *
C      *                                                                     *
C      *      VARIABLES USED IN THIS SECTION AND THEIR DEFAULT               *
C      *      VALUES ARE:                                                    *
C      *                                                                     *
C      *   1. RNSD(1.0)   : NORMAL SHOCK DIFFUSER COEFFICIENT                *
C      *   2. A4A3(1.0)   : SUBSONIC DIFFUSER EXIT-TO-ENTRANCE               *
C      *                    AREA RATIO                                       *
C      *   3. GP(1.400)   : RATIO OF SPECIFIC HEATS                          *
C      *   4. MWPMWS(1.0): PRIMARY-TO-SECONDARY MOLECULAR                    *
C      *                    WEIGHT RATIO                                     *
C      *   5. T60T50(1.0): PRIMARY-TO-SECONDARY STAGNATION                   *
C      *                    TEMPERATURE RATIO (FOR CAE)                      *
C      *   5. T60T20(1.0): PRIMARY-TO-SECONDARY STAGNATION                   *
C      *                    TEMPERATURE RATIO (FOR SSE)                      *
C      *   6. A8A7(1.0)   : SUBSONIC DIFFUSER EXIT-TO-ENTRANCE               *
C      *                    AREA RATIO                                       *
C      *                                                                     *
C      *      ALL VARIABLE INPUT IS BY NAMELIST.                             *
C      *                                                                     *
C      ***********************************************************************
C
C
102    WRITE(5,204)
       READ(5,205)EJECT
       IF(EJECT.EQ.SSE) GO TO 103
       WRITE(5,206)
       WRITE(5,DIFUSR)
       READ(5,DIFUSR)
       WRITE(5,207)
       WRITE(5,EJECT1)
       READ(5,EJECT1)
       GO TO 104
103    WRITE(5,207)
       WRITE(5,EJECT2)
       READ(5,EJECT2)
104    MWSMWP=1.0/MWPMWS
       T50T60=1.0/T60T50
       T20T60=1.0/T60T20
C
```

7.4.1 CLGDOP (Cont.)

```
C                                                                     CLGDOP 25100
C     ***************************************************************CLGDOP 25200
C     *                                                             * CLGDOP 25300
C     *          CACULATIONS FOR NORMAL SHOCK DIFFUSER              * CLGDOP 25400
C     *                                                             * CLGDOP 25500
C     ***************************************************************CLGDOP 25600
C                                                                     CLGDOP 25700
C                                                                     CLGDOP 25800
      IF(EJECT.EQ.SSE) GO TO 105                                      CLGDOP 25900
      CALL NSDS(GS,M2,RNSD,M3,P3P2,P30P20,T3T2,T30T20)                CLGDOP 26000
      P3P1=P3P2*P2P1                                                  CLGDOP 26100
      T3T1=T3T2*T2T1                                                  CLGDOP 26200
      P30P10=P30P20*P20P10                                            CLGDOP 26300
      T30T10=T30T20*T20T10                                            CLGDOP 26400
      A3A1=A2A1                                                       CLGDOP 26500
C                                                                     CLGDOP 26600
C                                                                     CLGDOP 26700
C     ***************************************************************CLGDOP 26800
C     *                                                             * CLGDOP 26900
C     *            CALCULATIONS FOR SUBSONIC DIFFUSER               * CLGDOP 27000
C     *                                                             * CLGDOP 27100
C     ***************************************************************CLGDOP 27200
C                                                                     CLGDOP 27300
C                                                                     CLGDOP 27400
      CALL SDS(GS,M3,A4A3,M4,P4P3,P40P30,T4T3,T40T30,RSD34,FAIL)      CLGDOP 27500
      IF(FAIL.EQ.YES) GO TO 120                                       CLGDOP 27600
      P4P1=P4P3*P3P1                                                  CLGDOP 27700
      T4T1=T4T3*T3T1                                                  CLGDOP 27800
      P40P10=P40P30*P30P10                                            CLGDOP 27900
      T40T10=T40T30*T30T10                                            CLGDOP 28000
      A4A1=A4A3*A3A1                                                  CLGDOP 28100
C                                                                     CLGDOP 28200
C                                                                     CLGDOP 28300
C     ***************************************************************CLGDOP 28400
C     *                                                             * CLGDOP 28500
C     *           CALCULATIONS FOR SUDDEN ENLARGEMENT               * CLGDOP 28600
C     *                                                             * CLGDOP 28700
C     ***************************************************************CLGDOP 28800
C                                                                     CLGDOP 28900
C                                                                     CLGDOP 29000
      P50P40=1.0                                                      CLGDOP 29100
      T50T40=1.0                                                      CLGDOP 29200
      P50P20=P50P40*P40P30*P30P20                                     CLGDOP 29300
      T50T20=T50T40*T40T30*T30T20                                     CLGDOP 29400
      P50P10=P50P20*P20P10                                            CLGDOP 29500
      T50T10=T50T20*T20T10                                            CLGDOP 29600
C                                                                     CLGDOP 29700
C                                                                     CLGDOP 29800
C     ***************************************************************CLGDOP 29900
C     *                                                             * CLGDOP 30000
```

7.4.1 CLGDOP (Cont.)

```
C     *           ITERATE M5 TO FIND MINIMUM XWPWS (XP60P1)            *
C     *                                                                *
C     ******************************************************************
C
C
      NTYPE1=1
      NIT1=1
      M5=1.0
      DO 114 ITER1=1,100
C
C     ******************************************************************
C     *                                                                *
C     *       ITERATE A7A6 TO FIND XP60P1=P60P1 (XWPWS=WPWS)           *
C     *                                                                *
C     ******************************************************************
C
C
105   NTYPE2=1
      NIT2=1
      A7A6=20.0
      DO 111 ITER2=1,100
C
C     ******************************************************************
C     *                                                                *
C     *                ITERATE M6 TO FIND XP8P1=P8P1                   *
C     *                                                                *
C     ******************************************************************
C
C
      NTYPE3=1
      NIT3=1
      M6=1.01
      DO 109 ITER3=1,100
C
C     ******************************************************************
C     *                                                                *
C     *           CALCULATICNS FOR CONSTANT-AREA EJECTOR               *
C     *                                                                *
C     ******************************************************************
C
C
      IF(EJECT.NE.CAE) GO TO 107
      A6A7=1.0/A7A6
      CALL CAES(GS,GP,MWSMWP,T50T60,M5,M6,A6A7,WSWP,GM,MWMMWP,
     -T70T60,M7,P60P50,P7P50,FAIL)
      IF(FAIL.EQ.YES) GO TO 121
      P7P1=P7P50*P50P20*P20P2*P2P1
```

7.4.1 CLGDOP (Cont.)

```
      P60P2=P60P50*P50P20*P20P2                                          CLGDOP 35100
      IF(FAIL.EQ.NO) GO TO 108                                           CLGDOP 35200
C                                                                        CLGDOP 35300
C                                                                        CLGDOP 35400
C     ***************************************************************    CLGDOP 35500
C     *                                                             *    CLGDOP 35600
C     *          NO CAE SOLUTION EXISTS FOR CURRENT VALUE OF        *    CLGDOP 35700
C     *          M6.  INCREMENT M6 AND SEARCH FOR SOLUTION.         *    CLGDOP 35800
C     *                                                             *    CLGDOP 35900
C     ***************************************************************    CLGDOP 36000
C                                                                        CLGDOP 36100
C                                                                        CLGDOP 36200
      M6=M6+0.5                                                          CLGDOP 36300
      IF(M6.GT.10.0) GO TO 106                                           CLGDOP 36400
      FAIL=NO                                                            CLGDOP 36500
      GO TO 109                                                          CLGDOP 36600
C                                                                        CLGDOP 36700
C                                                                        CLGDOP 36800
C     ***************************************************************    CLGDOP 36900
C     *                                                             *    CLGDOP 37000
C     *     NO CAE SOLUTION EXISTS FOR CURRENT VALUE OF A7A6.       *    CLGDOP 37100
C     *     INCREMENT A7A6 AND SEARCH FOR SOLUTION.                 *    CLGDOP 37200
C     *                                                             *    CLGDOP 37300
C     ***************************************************************    CLGDOP 37400
C                                                                        CLGDOP 37500
C                                                                        CLGDOP 37600
106   A7A6=A7A6-0.5                                                      CLGDOP 37700
      IF(A7A6.LE.1.0) GO TO 113                                          CLGDOP 37800
      FAIL=NO                                                            CLGDOP 37900
      GO TO 111                                                          CLGDOP 38000
C                                                                        CLGDOP 38100
C                                                                        CLGDOP 38200
C     ***************************************************************    CLGDOP 38300
C     *                                                             *    CLGDOP 38400
C     *        CALCULATIONS FOR SUPERSONIC-SUPERSONIC EJECTOR       *    CLGDOP 38500
C     *                                                             *    CLGDOP 38600
C     ***************************************************************    CLGDOP 38700
C                                                                        CLGDOP 38800
C                                                                        CLGDOP 38900
107   A2A6=A7A6-1.0                                                      CLGDOP 39000
      CALL SSES(GS,GP,MWSMWP,T20T60,M2,M6,A2A6,WSWP,GM,MWMMWP,           CLGDOP 39100
     -T70T60,M7,P60P2,P7P2,FAIL)                                         CLGDOP 39200
      IF(FAIL.EQ.YES) GO TO 122                                          CLGDOP 39300
      P7P1=P7P2*P2P1                                                     CLGDOP 39400
C                                                                        CLGDOP 39500
C                                                                        CLGDOP 39600
C     ***************************************************************    CLGDOP 39700
C     *                                                             *    CLGDOP 39800
C     *               CALCULATIONS FOR SUBSONIC DIFFUSER            *    CLGDOP 39900
C     *                                                             *    CLGDOP 40000
```

```
C       ************************************************************
C
C
108     CALL SDS(GM,M7,A8A7,M8,P8P7,P80P70,T8T7,T80T70,RSD78,FAIL)
        IF(FAIL.EQ.YES) GO TO 123
        XP8P1=P8P7*P7P1
C
C
C       ************************************************************
C       *                                                          *
C       *          TEST FOR XP8P1=P8P1 AND INCREMENT M6            *
C       *                                                          *
C       ************************************************************
C
C
        CALL ITER(M6,0.5,5.0E-06,+1.0,XP8P1,P8P1,1.0E-01,NIT3,
       -NTYPE3,XNEG3,YNEG3,XPOS3,YPOS3,NSIGN3,NSIGN4)
        IF(NTYPE3.EQ.3) GO TO 110
109     CONTINUE
        GO TO 125
C
C
C       ************************************************************
C       *                                                          *
C       *  TEST FOR XP60P1=P60P1 (XWPWS=WPWS) AND INCREMENT A7A6   *
C       *                                                          *
C       ************************************************************
C
C
110     XP60P1=P60P2*P2P1
        XWPWS=1.0/WSWP
        IF(COEFF.EQ.WPWSC) CALL ITER(A7A6,0.5,5.0E-06,-1.0,XP60P1,
       -P60P1,1.0E-01,NIT2,NTYPE2,XNEG2,YNEG2,XPOS2,YPOS2,NSIGN1,
       -NSIGN2)
        IF(COEFF.EQ.P60P1C) CALL ITER(A7A6,0.5,5.0E-06,-1.0,XWPWS,
       -WPWS,1.0E-01,NIT2,NTYPE2,XNEG2,YNEG2,XPOS2,YPOS2,NSIGN1,
       -NSIGN2)
        IF(NTYPE2.EQ.3) GO TO 112
111     CONTINUE
        GO TO 126
C
C
C       ************************************************************
C       *                                                          *
C       *  IF NO CAE SOLUTION EXISTS FOR CURRENT VALUE OF M5,      *
C       *  INCREMENT M5 AND SEARCH FOR SOLUTION.  IF SOLUTION      *
C       *  FOUND, TEST FOR MINIMUM XWPWS (XP60P1) AND INCREMENT    *
C       *  M5.                                                     *
C       *                                                          *
C       ************************************************************
```

7.4.1 CLGDOP (Cont.)

```
C                                                                       CLGDOP 45100
C                                                                       CLGDOP 45200
 112  IF(EJECT.EQ.SSE) GO TO 115                                        CLGDOP 45300
 113  IF(COEFF.EQ.WPWSC) CALL MIN(M5,XWPWS,NTYPE1,NIT1,COEFF,           CLGDOP 45400
     -FAIL)                                                             CLGDOP 45500
      IF(COEFF.EQ.P60P1C) CALL MIN(M5,XP60P1,NTYPE1,NIT1,COEFF,         CLGDOP 45600
     -FAIL)                                                             CLGDOP 45700
      IF(FAIL.EQ.YES) GO TO 124                                         CLGDOP 45800
 114  IF(NTYPE1.EQ.4) GC TO 115                                         CLGDOP 45900
      GO TO 127                                                         CLGDOP 46000
 115  MWMMWS=MWMMWP*MWPMWS                                              CLGDOP 46100
      WMWS=1.0+XWPWS                                                    CLGDOP 46200
C                                                                       CLGDOP 46300
C                                                                       CLGDOP 46400
C     ***********************************************************       CLGDOP 46500
C     *                                                         *       CLGDOP 46600
C     *            FINAL CALCULATIONS FOR CAE                   *       CLGDOP 46700
C     *                                                         *       CLGDOP 46800
C     ***********************************************************       CLGDOP 46900
C                                                                       CLGDOP 47000
      IF(EJECT.EQ.SSE) GO TO 116                                        CLGDOP 47100
      P5P1=P50P20*P20P2*P2P1/POPM(GS,M5)                                CLGDOP 47200
      T5T1=T50T20*T2CT2*T2T1/TOTM(GS,M5)                                CLGDOP 47300
      A5A1=SQRT(T50T10)*WM(GS,M1)/(P5P1*WM(GS,M5))                      CLGDOP 47400
      P70P50=POPM(GM,M7)*P7P50                                          CLGDOP 47500
      T70T50=T7CT60*T60T50                                              CLGDOP 47600
      T7T50=T70T50/TCTM(GM,M7)                                          CLGDOP 47700
      GO TO 117                                                         CLGDOP 47800
C                                                                       CLGDOP 47900
C                                                                       CLGDOP 48000
C     ***********************************************************       CLGDOP 48100
C     *                                                         *       CLGDOP 48200
C     *            FINAL CALCULATICNS FOR SSE                   *       CLGDOP 48300
C     *                                                         *       CLGDOP 48400
C     ***********************************************************       CLGDOP 48500
C                                                                       CLGDOP 48600
C                                                                       CLGDOP 48700
 116  P60P20=P6CP2/P20P2                                                CLGDOP 48800
      P70P20=POPM(GM,M7)*P7P2/P20P2                                     CLGDOP 48900
      T70T20=T7CT60*T60T20                                              CLGDOP 49000
      T7T2=T20T2*T70T20/TOTM(GM,M7)                                     CLGDOP 49100
      A7A2=A7A6/A2A6                                                    CLGDOP 49200
      GO TO 118                                                         CLGDOP 49300
C                                                                       CLGDOP 49400
C                                                                       CLGDOP 49500
C     ***********************************************************       CLGDOP 49600
C     *                                                         *       CLGDOP 49700
C     *         FINAL CALCULATIONS FOR NSD-SD-SE-CAE            *       CLGDOP 49800
C     *                                                         *       CLGDOP 49900
                                                                        CLGDOP 50000
```

7.4.1 CLGDOP (Cont.)

```
C     ********************************************************** CLGDOP 50100
C                                                                 CLGDOP 50200
C                                                                 CLGDOP 50300
117   P60P20=P60P50*P50P20                                        CLGDOP 50400
      T60T20=T60T50*T50T20                                        CLGDOP 50500
      P7P2=P7P50*P50P20*P20P2                                     CLGDOP 50600
      P70P20=P70P50*P50P20                                        CLGDOP 50700
      T7T2=T7T50*T50T20*T20T2                                     CLGDOP 50800
      T70T20=T70T50*T50T20                                        CLGDOP 50900
      A7A2=WMWS*SQRT(T70T20/MWMMWS)*WM(GS,M2)/(P7P2*WM(GM,M7))    CLGDOP 51000
C                                                                 CLGDOP 51100
C                                                                 CLGDOP 51200
C     ********************************************************** CLGDOP 51300
C     *                                                        * CLGDOP 51400
C     *    FINAL CALCULATIONS FOR NSD-SD-SE-CAE-SD OR SSE-SD   * CLGDOP 51500
C     *                                                        * CLGDOP 51600
C     ********************************************************** CLGDOP 51700
C                                                                 CLGDOP 51800
C                                                                 CLGDOP 51900
118   P8P2=P8P7*P7P2                                              CLGDOP 52000
      P80P20=P80P70*P70P20                                        CLGDOP 52100
      T8T2=T8T7*T7T2                                              CLGDOP 52200
      T80T20=T80T70*T70T20                                        CLGDOP 52300
C                                                                 CLGDOP 52400
C                                                                 CLGDOP 52500
C     ********************************************************** CLGDOP 52600
C     *                                                        * CLGDOP 52700
C     *               FINAL SYSTEM CALCULATIONS                * CLGDOP 52800
C     *                                                        * CLGDOP 52900
C     ********************************************************** CLGDOP 53000
C                                                                 CLGDOP 53100
C                                                                 CLGDOP 53200
      A7A1=A7A2*A2A1                                              CLGDOP 53300
      A6A1=A7A1/A7A6                                              CLGDOP 53400
      A8A1=A8A7*A7A1                                              CLGDOP 53500
      P60P10=P60P20*P20P10                                        CLGDOP 53600
      T60T1=T60T20*T20T2*T2T1                                     CLGDOP 53700
      T60T10=T60T20*T20T10                                        CLGDOP 53800
      P7P1=P7P2*P2P1                                              CLGDOP 53900
      P70P10=P70P20*P20P10                                        CLGDOP 54000
      T7T1=T7T2*T2T1                                              CLGDOP 54100
      T70T10=T70T20*T20T10                                        CLGDOP 54200
      P80P10=P80P20*P20P10                                        CLGDOP 54300
      T8T1=T8T2*T2T1                                              CLGDOP 54400
      T80T10=T80T20*T20T10                                        CLGDOP 54500
C                                                                 CLGDOP 54600
C                                                                 CLGDOP 54700
C     ********************************************************** CLGDOP 54800
C     *                                                        * CLGDOP 54900
C     *                    OUTPUT RESULTS                      * CLGDOP 55000
```

7.4.1 CLGDOP (Cont.)

```
C      *                                                          *      CLGDOP 55100
C      ************************************************************      CLGDOP 55200
C                                                                        CLGDOP 55300
C                                                                        CLGDOP 55400
       CALL TTY                                                          CLGDOP 55500
       GO TO 128                                                         CLGDOP 55600
C                                                                        CLGDOP 55700
C                                                                        CLGDOP 55800
C      ************************************************************      CLGDOP 55900
C      *                                                          *      CLGDOP 56000
C      *                   FAILURE INDICATORS                     *      CLGDOP 56100
C      *                                                          *      CLGDOP 56200
C      ************************************************************      CLGDOP 56300
C                                                                        CLGDOP 56400
C                                                                        CLGDOP 56500
119    WRITE(5,300)                                                      CLGDOP 56600
       GO TO 128                                                         CLGDOP 56700
120    WRITE(5,301)                                                      CLGDOP 56800
       GO TO 128                                                         CLGDOP 56900
121    WRITE(5,302)                                                      CLGDOP 57000
       GO TO 128                                                         CLGDOP 57100
122    WRITE(5,303)                                                      CLGDOP 57200
       GO TO 128                                                         CLGDOP 57300
123    WRITE(5,304)                                                      CLGDOP 57400
       GO TO 128                                                         CLGDOP 57500
124    WRITE(5,305)                                                      CLGDOP 57600
125    WRITE(5,306)M5,A7A6,M6,XP8P1,P8P1                                 CLGDOP 57700
       GO TO 128                                                         CLGDOP 57800
126    IF(COEFF.EQ.WPWSC) WRITE(5,307)M5,M6,A7A6,XP60P1,P60P1            CLGDOP 57900
       IF(COEFF.EQ.P60P1C) WRITE(5,308)M5,M6,A7A6,XWPWS,WPWS             CLGDOP 58000
       GO TO 128                                                         CLGDOP 58100
127    IF(COEFF.EQ.WPWSC) WRITE(5,309)M6,A7A6,M5,XWPWS                   CLGDOP 58200
       IF(COEFF.EQ.P60P1C) WRITE(5,310)M6,A7A6,M5,XP60P1                 CLGDOP 58300
128    WRITE(5,208)                                                      CLGDOP 58400
       READ(5,209)RUN                                                    CLGDOP 58500
       IF(RUN.EQ.YES) GO TO 100                                          CLGDOP 58600
C                                                                        CLGDOP 58700
C                                                                        CLGDOP 58800
C      ************************************************************      CLGDOP 58900
C      *                                                          *      CLGDOP 59000
C      *                   FORMAT STATEMENTS                      *      CLGDOP 59100
C      *                                                          *      CLGDOP 59200
C      ************************************************************      CLGDOP 59300
C                                                                        CLGDOP 59400
C                                                                        CLGDOP 59500
200    FORMAT('0',T2,'INPUT DATA FOR LASER CAVITY ANALYSIS BY ',         CLGDOP 59600
      -'NAMELIST.',/,T2,'CURRENT VALUES ARE:',/)                         CLGDOP 59700
201    FORMAT('0',T2,'INPUT THE VARIABLE TO BE MINIMIZED FROM ',         CLGDOP 59800
      -'THE FOLLOWING LIST:',//,T2,                                      CLGDOP 59900
      -'"P60P1" DIMENSIONLESS PRIMARY STAGNATION PRESSURE',/,T2,         CLGDOP 60000
```

7.4.1 CLGDOP (Cont.)

```
     -'"WPWS"  PRIMARY-TO-SECONDARY MASS FLOW RATIO',/)
 202  FORMAT(A5)
 203  FORMAT('0',T2,'INPUT SYSTEM CONSTRAINTS BY NAMELIST.',/,
     -T2,'CURRENT VALUES ARE:',/)
 204  FORMAT('0',T2,'INPUT THE EJECTOR MODEL FROM THE ',
     -'FOLLOWING LIST:',//,T2,
     -'"CAE" CONSTANT-AREA EJECTOR',/,T2,
     -'"SSE" SUPERSONIC-SUPERSONIC EJECTOR',/)
 205  FORMAT(A3)
 206  FORMAT('0',T2,'INPUT DATA FOR SUPERSONIC-SUBSONIC ',
     -'DIFFUSER SECTION BY NAMELIST.',/,T2,'CURRENT VALUES ARE:',
     -/)
 207  FORMAT('0',T2,'INPUT DATA FOR EJECTOR ANALYSIS BY ',
     -'NAMELIST.',/,T2,'CURRENT VALUES ARE:',/)
 208  FORMAT('1',T2,'TO RESTART PROGRAM ENTER "YES"',/,T2,
     -'TO STOP PROGRAM ENTER "NO"')
 209  FORMAT(A3)
C
 300  FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE CAVITY')
 301  FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE SDS',/,
     -T2,'AT STATION 3 TO 4 IN CHEMICAL LASER SYSTEM')
 302  FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE CAES')
 303  FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE SSES')
 304  FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE SDS',/,
     -T2,'AT STATION 7 TO 8 IN CHEMICAL LASER SYSTEM')
 305  FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE MIN')
 306  FORMAT('0',T2,'CONVERGENCE FAILURE IN MAIN PROGRAM',/,
     -T2,'FOR M6 SUCH THAT XP8P1=P8P1',//,
     -T2,'M5     =',E13.6,T26,'A7A6    =',E13.6,/,
     -T2,'M6     =',E13.6,T26,'XP8P1   =',E13.6,/,
     -T2,'P8P1   =',E13.6)
 307  FORMAT('0',T2,'CONVERGENCE FAILURE IN MAIN PROGRAM',/,
     -T2,'FOR A7A6 SUCH THAT XP60P1=P60P1',//,
     -T2,'M5     =',E13.6,T26,'M6      =',E13.6,/,
     -T2,'A7A6   =',E13.6,T26,'XP60P1  =',E13.6,/,
     -T2,'P60P1  =',E13.6)
 308  FORMAT('0',T2,'CONVERGENCE FAILURE IN MAIN PROGRAM',/,
     -T2,'FOR A7A6 SUCH THAT XWPWS=WPWS',//,
     -T2,'M5     =',E13.6,T26,'M6      =',E13.6,/,
     -T2,'A7A6   =',E13.6,T26,'XWPWS   =',E13.6,/,
     -T2,'WPWS   =',E13.6)
 309  FORMAT('0',T2,'CONVERGENCE FAILURE IN MAIN PROGRAM',/,
     -T2,'FOR M5 SUCH THAT XWPWS = MINIMUM WPWS',//,
     -T2,'M6     =',E13.6,T26,'A7A6    =',E13.6,/,
     -T2,'M5     =',E13.6,T26,'XWPWS   =',E13.6)
 310  FORMAT('0',T2,'CONVERGENCE FAILURE IN MAIN PROGRAM',/,
     -T2,'FOR M5 SUCH THAT XP60P1 = MINIMUM P60P1',//,
     -T2,'M6     =',E13.6,T26,'A7A6    =',E13.6,/,
     -T2,'M5     =',E13.6,T26,'XP60P1 =',E13.6)
      END
```

7.4.1 CLGDOP (Cont.)

```
C      ***********************************************************
C      *                                                         *
C      *              LASER CAVITY SUBROUTINE (CAVITY)           *
C      *                                                         *
C      ***********************************************************
C
C      ***********************************************************
C      *                                                         *
C      *   SUBROUTINE CAVITY IS A SIMPLIFIED FLOW MODEL TO       *
C      *   ASSESS QUALITATIVELY THE EFFECTS OF HEAT RELEASE AND  *
C      *   AREA CHANGE ON THE LASER CAVITY FLOW.  THE FLOW MODEL *
C      *   IS BASED ON THE ASSUMPTION OF A 1-D FLOW OF AN IDEAL  *
C      *   HOMOGENEOUS GAS THROUGH A CHANNEL WITH A LINEAR       *
C      *   VARIATION IN AREA AND HEAT ADDITION.                  *
C      *                                                         *
C      *   INPUT VARIABLES:                                      *
C      *                                                         *
C      *   G       = SPECIFIC HEAT RATIO                         *
C      *   M1      = ENTRANCE MACH NUMBER                        *
C      *   X1      = ENTRANCE COORDINATE                         *
C      *   X2      = EXIT COORDINATE                             *
C      *   A1      = ENTRANCE AREA                               *
C      *   A2      = EXIT AREA                                   *
C      *   CQ1     = HEAT ADDITION COEFFICIENT                   *
C      *   CQ2     = HEAT ADDITION COEFFICIENT                   *
C      *   NPTS    = CAVITY INTEGRATION INCREMENTS               *
C      *                                                         *
C      *   OUTPUT VARIABLES:                                     *
C      *                                                         *
C      *   M2      = EXIT MACH NUMBER                            *
C      *   T2      = EXIT STATIC TEMPERATURE                     *
C      *   T02     = EXIT STAGNATION TEMPERATURE                 *
C      *   P2      = EXIT STATIC PRESSURE                        *
C      *   P02     = EXIT STAGNATION PRESSURE                    *
C      *   FAIL    = ERROR FLAG                                  *
C      *                                                         *
C      ***********************************************************
C
       SUBROUTINE CAVITY(G,M1,DUMMY1,DUMMY2,A1,A2,CQ1,CQ2,NPTS,
      -M2,T2,T02,P2,P02,FAIL)
C
       EXTERNAL FMSQD
       IMPLICIT REAL*4(L,M)
       DIMENSION T0(25)
       COMMON/FVD/ZI(3),XI(3),X(25),M(25),P(25),P0(25),T(25)
       COMMON/COEFF/X1,CA(2),CT0(2)
       DATA YES/'YES'/
C
C
```

7.4.1 CLGDOP (Cont.)

```
C     ****************************************************************   CAVITY 05100
C     *                                                              *   CAVITY 05200
C     *           INITIALIZE VARIABLES AT STATION (1).               *   CAVITY 05300
C     *                                                              *   CAVITY 05400
C     ****************************************************************   CAVITY 05500
C                                                                        CAVITY 05600
C                                                                        CAVITY 05700
      X1=DUMMY1                                                          CAVITY 05800
      X2=DUMMY2                                                          CAVITY 05900
      X(1)=X1                                                            CAVITY 06000
      M(1)=M1                                                            CAVITY 06100
      P(1)=1.C                                                           CAVITY 06200
      PO(1)=1.0                                                          CAVITY 06300
      T(1)=1.0                                                           CAVITY 06400
      TO(1)=1.0                                                          CAVITY 06500
      XRKI=X1                                                            CAVITY 06600
      YRKI=M1**2                                                         CAVITY 06700
C                                                                        CAVITY 06800
C                                                                        CAVITY 06900
C     ****************************************************************   CAVITY 07000
C     *                                                              *   CAVITY 07100
C     *  CALCULATE THE CAVITY AREA COEFFICIENTS.  A LINEAR           *   CAVITY 07200
C     *  VARIATION WITH X IS ASSUMED.                                *   CAVITY 07300
C     *                                                              *   CAVITY 07400
C     ****************************************************************   CAVITY 07500
C                                                                        CAVITY 07600
C                                                                        CAVITY 07700
      CA(1)=(A1*X2-A2*X1)/(X2-X1)                                        CAVITY 07800
      CA(2)=(A2-A1)/(X2-X1)                                              CAVITY 07900
C                                                                        CAVITY 08000
C                                                                        CAVITY 08100
C     ****************************************************************   CAVITY 08200
C     *                                                              *   CAVITY 08300
C     *  CALCULATE THE RATE OF HEAT ADDITION COEFFICIENTS.  A        *   CAVITY 08400
C     *  LINEAR VARIATION OF RATE OF HEAT ADDITION WITH X IS         *   CAVITY 08500
C     *  ASSUMED.                                                    *   CAVITY 08600
C     *                                                              *   CAVITY 08700
C     ****************************************************************   CAVITY 08800
C                                                                        CAVITY 08900
C                                                                        CAVITY 09000
      CTO(1)=(CQ1*X2-CQ2*X1)/(X2-X1)                                     CAVITY 09100
      CTO(2)=(CQ2-CQ1)/(X2-X1)                                           CAVITY 09200
C                                                                        CAVITY 09300
C                                                                        CAVITY 09400
C     ****************************************************************   CAVITY 09500
C     *                                                              *   CAVITY 09600
C     *        INITIALIZE FLOW VARIABLES FOR INTEGRATION.            *   CAVITY 09700
C     *                                                              *   CAVITY 09800
C     ****************************************************************   CAVITY 09900
C                                                                        CAVITY 10000
```

7.4.1 CLGDCP (Cont.)

```
C
      LNP=0.0
      LNPO=0.0
      LNT=0.0
C
C
C     ************************************************************
C     *                                                          *
C     *  SET INCREMENT SIZE FOR R-K AND SIMPSON INTEGRATIONS.    *
C     *                                                          *
C     ************************************************************
C
C
      DX=(X2-X1)/FLOAT(NPTS-1)
      DXRKI=DX/2.0
C
C
C     ************************************************************
C     *                                                          *
C     *                  INTEGRATION SECTION                     *
C     *                                                          *
C     ************************************************************
C
C
      DO 60 I=2,NPTS
C
C
C     ************************************************************
C     *                                                          *
C     *       SET-UP FOR D(M**2)/DX INTEGRATION BY R-K.          *
C     *                                                          *
C     ************************************************************
C
C
      ZI(1)=YRKI
      XI(1)=XRKI
      DO 50 J=1,2
C
C
C     ************************************************************
C     *                                                          *
C     *              INTEGRATE D(M**2)/DX BY R-K.                *
C     *                                                          *
C     ************************************************************
C
C
      CALL RKI1(G,DXRKI,XRKI,YRKI,FMSQD,FAIL)
      IF(FAIL.EQ.YES) GO TO 110
      XI(J+1)=XRKI
      ZI(J+1)=YRKI
```

```
 50   CONTINUE                                                           CAVITY 15100
C                                                                        CAVITY 15200
C                                                                        CAVITY 15300
C     ***********************************************************        CAVITY 15400
C     *                                                         *        CAVITY 15500
C     *       INTEGRATE TO FIND P,PO,T BY SIMPSON'S RULE.       *        CAVITY 15600
C     *                                                         *        CAVITY 15700
C     ***********************************************************        CAVITY 15800
C                                                                        CAVITY 15900
C                                                                        CAVITY 16000
      CALL FVI(I,G,DX,LNP,LNPO,LNT)                                      CAVITY 16100
C                                                                        CAVITY 16200
C                                                                        CAVITY 16300
C     ***********************************************************        CAVITY 16400
C     *                                                         *        CAVITY 16500
C     *  EVALUATE THE STAGNATION TEMPERATURE RATIO BASED ON A   *        CAVITY 16600
C     *  RATE OF HEAT ADDITION THAT IS ASSUMED TO BE A LINEAR   *        CAVITY 16700
C     *  FUNCTION OF X.                                         *        CAVITY 16800
C     *                                                         *        CAVITY 16900
C     ***********************************************************        CAVITY 17000
C                                                                        CAVITY 17100
C                                                                        CAVITY 17200
      TO(I)=(1.0+CTO(1)*(X(I)-X1)+0.5*CTO(2)*                            CAVITY 17300
     -(X(I)**2-X1**2))                                                   CAVITY 17400
 60   CONTINUE                                                           CAVITY 17500
      TO2=TO(NPTS)                                                       CAVITY 17600
      T2=T(NPTS)                                                         CAVITY 17700
      PO2=PO(NPTS)                                                       CAVITY 17800
      P2=P(NPTS)                                                         CAVITY 17900
      M2=M(NPTS)                                                         CAVITY 18000
 110  END                                                                CAVITY 18100
```

```
C     ***********************************************************
C     *                                                         *
C     *        RUNGE-KUTTA INTEGRATION SUBROUTINE (RKI1)        *
C     *               (OF SUBROUTINE CAVITY)                    *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *  SUBROUTINE RKI1 PERFORMS A FOURTH-ORDER RUNGE-KUTTA    *
C     *  INTEGRATION OF A FIRST-ORDER DIFFERENTIAL EQUATION...  *
C     *  DY/DX=F(P,X,Y) WHERE P IS A PARAMETER. THE SUBROUTINE  *
C     *  IS SPECIALIZED FOR 1-D FLOW WITH AREA CHANGE AND HEAT  *
C     *  ADDITION.                                              *
C     *                                                         *
C     ***********************************************************
C
C
      SUBROUTINE RKI1(P,DX,X,Y,F,FAIL)
C
      DATA YES/'YES'/
C
      N=0
      C1=F(P,X,Y)*DX
      XRK=X+0.5*DX
      YRK=Y+0.5*C1
      GO TO 40
   10 C2=F(P,XRK,YRK)*DX
      YRK=Y+0.5*C2
      GO TO 40
   20 C3=F(P,XRK,YRK)*DX
      XRK=X+DX
      YRK=Y+C3
      GO TO 40
   30 C4=F(P,XRK,YRK)*DX
      YRK=Y+(C1+2.0*(C2+C3)+C4)/6.0
   40 IF((Y .GT. 1) .AND. (YRK .LE. 1)) GO TO 50
      IF((Y .LT. 1) .AND. (YRK .GE. 1)) GO TO 50
      N=N+1
      GO TO (10,20,30,70), N
C
C     ***********************************************************
C     *                                                         *
C     *  TRANSITIONS FROM SUBSONIC-TO-SUPERSONIC FLOW OR        *
C     *  SUPERSONIC-TO-SUBSONIC FLOW ARE NOT ALLOWED IN THIS    *
C     *  PROGRAM.                                               *
C     *                                                         *
C     ***********************************************************
C
```

7.4.1 CLGDOP (Cont.)

```
C                                                                RKI1   05100
50    WRITE(5,60)                                                RKI1   05200
60    FORMAT(//,5X,'.....R-K INTEGRATION TERMINATED BECAUSE ',   RKI1   05300
     -'CHOKING WAS ENCOUNTERED.'/)                               RKI1   05400
      FAIL=YES                                                   RKI1   05500
      RETURN                                                     RKI1   05600
70    Y=YRK                                                      RKI1   05700
      X=XRK                                                      RKI1   05800
      END                                                        RKI1   05900
```

```
C     ***********************************************************
C     *                                                         *
C     *        FLOW VARIABLE INTEGRATICN SUBROUTINE (FVI)       *
C     *              (OF SUBROUTINE CAVITY)                     *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *  SUBROUTINE FVI PERFORMS AN INTEGRATION BY SIMPSON'S    *
C     *  RULE TO FIND THE FLOW VARIABLES (M,P,PO,T) ALONG THE   *
C     *  LASER CAVITY AS A FUNCTION OF X.  THE VARIABLES ARE    *
C     *  FOUND BY INTEGRATING EQUATIONS OF THE FORM...          *
C     *  DY/DX=F(G,Z(X),X).  REFERENCE: SHAPIRO, PAGE 231.      *
C     *                                                         *
C     *  ALL VARIABLES ARE NON-DIMENSIONALIZED WITH RESPECT TO  *
C     *  THE LASER CAVITY ENTRANCE CONDITIONS.                  *
C     *                                                         *
C     ***********************************************************
C
C
      SUBROUTINE FVI(I,G,DX,LNP,LNPO,LNT)
C
      IMPLICIT REAL*4(L,M)
      COMMON/FVD/ZI(3),XI(3),X(25),M(25),P(25),PO(25),T(25)
C
C
C     ***********************************************************
C     *                                                         *
C     *        FUNCTIONS TO BE INTEGRATED WHERE Z=M**2.         *
C     *                                                         *
C     ***********************************************************
C
C
      FP(G,Z,X)=(G*Z/(1.-Z))*(FA(X)-(1.+0.5*(G-1.)*Z)*FTO(X))
      FPO(G,Z,X)=-0.5*G*Z*FTO(X)
      FT(G,Z,X)=((G-1.C)*Z/(1.0-Z))*FA(X)
     -+((1.0-G*Z)*(1.0+0.5*(G-1.0)*Z)/(1.0-Z))*FTO(X)
C
C
C     ***********************************************************
C     *                                                         *
C     *                SIMPSON'S RULE INTEGRATION.              *
C     *                                                         *
C     ***********************************************************
C
C
      DLNP=(DX/6.0)*(FP(G,ZI(1),XI(1))+4.0*FP(G,ZI(2),XI(2))
     -+FP(G,ZI(3),XI(3)))
      DLNT=(DX/6.0)*(FT(G,ZI(1),XI(1))+4.0*FT(G,ZI(2),XI(2))
```

7.4.1 CLGDOP (Cont.)

```
     -+FT(G,ZI(3),XI(3)))
      DLNPO=(DX/6.0)*(FPO(G,ZI(1),XI(1))+4.0*FPO(G,ZI(2),XI(2))
     -+FPO(G,ZI(3),XI(3)))
C
C
C     **************************************************************
C     *                                                            *
C     *   FIND THE NEW VALUES OF THE INTEGRATION VARIABLES.        *
C     *                                                            *
C     **************************************************************
C
C
      LNP=LNP+DLNP
      LNPO=LNPO+DLNPO
      LNT=LNT+DLNT
C
C
C     **************************************************************
C     *                                                            *
C     *  LASER CAVITY FLOW VARIABLES...V(I)-VS-X(I), I=1,NPTS.     *
C     *                                                            *
C     **************************************************************
C
C
      X(I)=XI(3)
      P(I)=EXP(LNP)
      PO(I)=EXP(LNPO)
      T(I)=EXP(LNT)
      M(I)=SQRT(ZI(3))
      END
```

7.4.1 CLGDOP (Cont.)

```
C     ******************************************************************
C     *                                                                *
C     *                    FUNCTION SUBPROGRAMS                        *
C     *                   (OF SUBROUTINE CAVITY)                       *
C     *                                                                *
C     ******************************************************************
C
C     ******************************************************************
C     *                                                                *
C     *           NOTE...Y=M**2 AND DY/DX=FMSQD(G,X,Y)                 *
C     *                                                                *
C     ******************************************************************
C
      FUNCTION FMSQD(G,X,Y)
      FMSQD=(Y*(1.0+0.5*(G-1.0)*Y)/(1.0-Y))*
     -(-2.0*FA(X)+(1.0+G*Y)*FTO(X))
      END
C
C     ******************************************************************
C     *                                                                *
C     *  FUNCTION FOR EVALUATING...(1.0/A)(DA/DX).  THE LASER          *
C     *  CAVITY AREA IS ASSUMED TO BE A LINEAR FUNCTION OF X.          *
C     *                                                                *
C     ******************************************************************
C
      FUNCTION FA(X)
      COMMON/COEFF/X1,CA(2),CTO(2)
      FA=CA(2)/(CA(1)+CA(2)*X)
      END
C
C     ******************************************************************
C     *                                                                *
C     *  FUNCTION FOR EVALUATING...(1.0/TO)(CTO/DX).  THE RATE         *
C     *  OF HEAT ADDITION IS ASSUMED TO BE A LINEAR FUNCTION           *
C     *  OF X.                                                         *
C     *                                                                *
C     ******************************************************************
C
      FUNCTION FTO(X)
      COMMON/COEFF/X1,CA(2),CTO(2)
      FTO=(CTO(1)+CTO(2)*X)/(1.0+CTO(1)*(X-X1)+0.5*CTO(2)*
     -(X**2-X1**2))
      END
```

7.4.1 CLGDOP (Cont.)

```
C     ****************************************************************
C     *                                                              *
C     *         NORMAL SHOCK DIFFUSER SUBROUTINE (NSDS)              *
C     *                                                              *
C     ****************************************************************
C
C     ****************************************************************
C     *                                                              *
C     *  SUBROUTINE NSDS CALCULATES THE PRESSURE RATIO ACROSS        *
C     *  A CONSTANT-AREA, SUPERSONIC DIFFUSER.  THE STATIC           *
C     *  PRESSURE RATIO IS TAKEN AS RD*(PY/PX) FOR A NORMAL          *
C     *  SHOCK AT THE ENTERING MACH NO.  ALL OTHER PROPERTIES        *
C     *  ARE CALCULATED FROM THE ISENTROPIC FLOW RELATIONS TO        *
C     *  BE CONSISTENT WITH THE ENTRANCE AND EXIT MACH NO.S.         *
C     *                                                              *
C     * INPUT VARIABLES:                                             *
C     *                                                              *
C     * G      = GAMMA                                               *
C     * M1     = ENTRANCE MACH NUMBER                                *
C     * RD     = NORMAL SHOCK DIFFUSER COEFFICIENT                   *
C     *                                                              *
C     * OUTPUT VARIABLES:                                            *
C     *                                                              *
C     * M2     = EXIT MACH NUMBER                                    *
C     * P2P1   = EXIT-TO-ENTRANCE STATIC PRESSURE RATIO              *
C     * P20P10 = EXIT-TO-ENTRANCE STAGNATION PRESSURE RATIO          *
C     * T2T1   = EXIT-TO-ENTRANCE STATIC TEMPERATURE RATIO           *
C     * T20T10 = EXIT-TO-ENTRANCE STAGNATION TEMPERATURE RATIO       *
C     *                                                              *
C     ****************************************************************
C
      SUBROUTINE NSDS(G,M1,RD,M2,P2P1,P20P10,T2T1,T20T10)
C
      IMPLICIT REAL*4(M)
C
      TOTM(GX,MX)=1.0+0.5*(GX-1.0)*MX*MX
      POPM(GX,MX)=(1.0+C.5*(GX-1.0)*MX*MX)**(GX/(GX-1.0))
C
      M2=SQRT((2.0+(G-1.0)*M1*M1)/(2.0*G*M1*M1-G+1.0))
      P2P1=RD*(2.0*G*M1*M1-G+1.0)/(G+1.0)
      P10P1=POPM(G,M1)
      P20P2=POPM(G,M2)
      P20P10=P2CP2*P2P1/P10P1
      T20T10=1.C
      T10T1=TOTM(G,M1)
      T20T2=TCTM(G,M2)
      T2T1=T10T1*T2CT10/T20T2
      END
```

```
C     ********************************************************         SDS   00100
C     *                                                      *         SDS   00200
C     *           SUBSONIC DIFFUSER SUBROUTINE (SDS)          *         SDS   00300
C     *                                                      *         SDS   00400
C     ********************************************************         SDS   00500
C                                                                      SDS   00600
C     ********************************************************         SDS   00700
C     *                                                      *         SDS   00800
C     *  SUBROUTINE SDS CALCULATES THE PRESSURE RATIO ACROSS A *       SDS   00900
C     *  CONICAL, SUBSONIC DIFFUSER WITH AN INCLUDED ANGLE OF  *       SDS   01000
C     *  15 DEGREES.  THE STATIC PRESSURE RATIO IS COMPUTED    *       SDS   01100
C     *  USING AN EMPERICAL DIFFUSER EFFICIENCY.  ALL OTHER    *       SDS   01200
C     *  PROPERTIES ARE CALCULATED FROM THE ISENTROPIC FLOW    *       SDS   01300
C     *  RELATIONS TO BE CONSISTENT WITH THE ENTRANCE AND EXIT *       SDS   01400
C     *  MACH NO.S.                                            *       SDS   01500
C     *                                                      *         SDS   01600
C     *  THE SUBSONIC DIFFUSER EFFICIENCY GIVEN BY:            *       SDS   01700
C     *                                                      *         SDS   01800
C     *                EFF=(P2'-P1)/(P2-P1)                    *       SDS   01900
C     *                                                      *         SDS   02000
C     *  IS LIMITED TO THE RANGE: 0.2<M1<0.5, 2.34<A2/A1<5.2   *       SDS   02100
C     *  AND IS DERIVED FROM DATA IN THE FOLLOWING REFERENCES: *       SDS   02200
C     *                                                      *         SDS   02300
C     *  HENRY,J.R., WOOD,C.C., AND WILBUR,S.W., "SUMMARY OF   *       SDS   02400
C     *  SUBSONIC-DIFFUSER DATA." NACA RM L56F05 (1956).       *       SDS   02500
C     *                                                      *         SDS   02600
C     *  PATTERSON,G.N., "MODERN DIFFUSER DESIGN," AIRCRAFT    *       SDS   02700
C     *  ENGINEERING, 9(9):267-273 (1938).                     *       SDS   02800
C     *                                                      *         SDS   02900
C     *  THE SUBSONIC DIFFUSER COEFFICIENT IS DEFINED AS:      *       SDS   03000
C     *                                                      *         SDS   03100
C     *                RD=(P2'/P1)/(P2/P1)                     *       SDS   03200
C     *                                                      *         SDS   03300
C     * INPUT VARIABLES:                                       *       SDS   03400
C     *                                                      *         SDS   03500
C     * G      = GAMMA                                         *       SDS   03600
C     * M1     = ENTRANCE MACH NUMBER                          *       SDS   03700
C     * A2A1   = EXIT-TO-ENTRANCE AREA RATIO                   *       SDS   03800
C     *                                                      *         SDS   03900
C     * OUTPUT VARIABLES:                                      *       SDS   04000
C     *                                                      *         SDS   04100
C     * M2     = EXIT MACH NUMBER                              *       SDS   04200
C     * P2P1   = EXIT-TO-ENTRANCE STATIC PRESSURE RATIO        *       SDS   04300
C     * P20P10 = EXIT-TO-ENTRANCE STAGNATION PRESSURE RATIO    *       SDS   04400
C     * T2T1   = EXIT-TO-ENTRANCE STATIC TEMPERATURE RATIO     *       SDS   04500
C     * T20T10 = EXIT-TO-ENTRANCE STAGNATION TEMPERATURE RATIO *       SDS   04600
C     * RD     = SUBSONIC DIFFUSER COEFFICIENT                 *       SDS   04700
C     * FAIL   = ERROR FLAG                                    *       SDS   04800
C     *                                                      *         SDS   04900
C     ********************************************************         SDS   05000
```

7.4.1 CLGDOP (Cont.)

```
C
C
      SUBROUTINE SDS(G,M1,A2A1,M2,P2P1,P20P10,T2T1,T2?T10,RD,
     -FAIL)
C
      IMPLICIT REAL*4(M)
      DATA YES/'YES'/,SUB/'SUB'/
C
C     ***********************************************************
C     *                                                         *
C     *                 GAS DYNAMIC FUNCTIONS                   *
C     *                                                         *
C     ***********************************************************
C
C
      TOTM(GX,MX)=1.0+0.5*(GX-1.0)*MX*MX
      POPM(GX,MX)=(1.0+0.5*(GX-1.0)*MX*MX)**(GX/(GX-1.0))
C
C
C     ***********************************************************
C     *                                                         *
C     *       CALCULATIONS FOR CONSTANT-AREA DIFFUSER           *
C     *                                                         *
C     ***********************************************************
C
C
      IF(A2A1.NE.1.0) GO TO 1
      M2=M1
      P2P1=1.0
      P20P10=1.0
      T2T1=1.0
      T20T10=1.0
      RD=1.0
      RETURN
C
C
C     ***********************************************************
C     *                                                         *
C     *                 CALCULATE CONSTANTS                     *
C     *                                                         *
C     ***********************************************************
C
C
    1 G2=2.0/(G+1.0)
      G4=(G+1.0)/(2.0*(G-1.0))
C
C
C     ***********************************************************
C     *                                                         *
```

7.4.1 CLGDOP (Cont.)

```
C     *                       SOLVE A2A2S FOR M2                       *     SDS   10100
C     *                                                                *     SDS   10200
C     ******************************************************************     SDS   10300
C                                                                            SDS   10400
C                                                                            SDS   10500
      A1A1S=(1.0/M1)*(G2*TOTM(G,M1))**G4                                     SDS   10600
      A2A2S=A2A1*A1A1S                                                       SDS   10700
      CALL MAAS(G,M1,A2A2S,SUB,5.0E-06,M2,FAIL)                              SDS   10800
      IF(FAIL.EQ.YES) RETURN                                                 SDS   10900
C                                                                            SDS   11000
C                                                                            SDS   11100
C     ******************************************************************     SDS   11200
C     *                                                                *     SDS   11300
C     *             CALCULATE THE DIFFUSER EFFICIENCY                  *     SDS   11400
C     *                                                                *     SDS   11500
C     ******************************************************************     SDS   11600
C                                                                            SDS   11700
C                                                                            SDS   11800
      EFF=0.002685*A2A1*A2A1*A2A1-0.024461*A2A1*A2A1-0.027229*               SDS   11900
     -A2A1+1.048992                                                          SDS   12000
C                                                                            SDS   12100
C                                                                            SDS   12200
C     ******************************************************************     SDS   12300
C     *                                                                *     SDS   12400
C     *         CALCULATE THE IDEAL STATIC PRESSURE RATIO              *     SDS   12500
C     *                                                                *     SDS   12600
C     ******************************************************************     SDS   12700
C                                                                            SDS   12800
C                                                                            SDS   12900
      P1OP1=POPM(G,M1)                                                       SDS   13000
      P2OP2=POPM(G,M2)                                                       SDS   13100
      P2P1=P1OP1/P2OP2                                                       SDS   13200
      RD=EFF+(1.0-EFF)/P2P1                                                  SDS   13300
C                                                                            SDS   13400
C                                                                            SDS   13500
C     ******************************************************************     SDS   13600
C     *                                                                *     SDS   13700
C     *         CALCULATE THE ACTUAL STATIC PRESSURE RATIO             *     SDS   13800
C     *                                                                *     SDS   13900
C     ******************************************************************     SDS   14000
C                                                                            SDS   14100
C                                                                            SDS   14200
      P2P1=RD*P2P1                                                           SDS   14300
      P2OP1O=P2OP2*P2P1/P1OP1                                                SDS   14400
      T2OT1O=1.0                                                             SDS   14500
      T1OT1=TOTM(G,M1)                                                       SDS   14600
      T2OT2=TOTM(G,M2)                                                       SDS   14700
      T2T1=T1OT1*T2OT1O/T2OT2                                                SDS   14800
      END                                                                    SDS   14900
```

```
C      ************************************************************
C      *                                                          *
C      *        CONSTANT-AREA EJECTOR SUBROUTINE (CAES)           *
C      *                                                          *
C      ************************************************************
C
C      ************************************************************
C      *                                                          *
C      *  SUBROUTINE CAES CALCULATES THE BREAK-OFF COMPRESSION    *
C      *  RATIO FOR A CONSTANT-AREA, SUBSONIC-SUPERSONIC          *
C      *  EJECTOR BY A ONE-DIMENSIONAL ANALYSIS.                  *
C      *                                                          *
C      *  INPUT VARIABLES:                                        *
C      *                                                          *
C      *  GS     = SECONDARY GAMMA                                *
C      *  GP     = PRIMARY GAMMA                                  *
C      *  MWSP   = SECONDARY-TO-PRIMARY MOLECULAR WEIGHT RATIO    *
C      *  TSOPO  = SECONDARY-TO-PRIMARY STAGNATION TEMPERATURE    *
C      *           RATIO                                          *
C      *  MS1    = SECONDARY MACH NO. AT THE MIXING TUBE          *
C      *           ENTRANCE                                       *
C      *  MP1    = PRIMARY MACH NO. AT THE MIXING TUBE ENTRANCE   *
C      *  AP1M3  = PRIMARY-TO-MIXING TUBE AREA RATIO              *
C      *                                                          *
C      *  OUTPUT VARIABLES:                                       *
C      *                                                          *
C      *  WSP    = SECONDARY-TO-PRIMARY MASS FLOW RATIO           *
C      *  GM     = MIXED STREAM GAMMA                             *
C      *  MWMP   = MIXED STREAM-TO-PRIMARY MOLECULAR WEIGHT       *
C      *           RATIO                                          *
C      *  TMOPO  = MIXED STREAM-TO-PRIMARY STAGNATION             *
C      *           TEMPERATURE RATIO                              *
C      *  MM3    = MIXED STREAM MACH NO. AT THE MIXING TUBE       *
C      *           EXIT                                           *
C      *  PPOSO  = PRIMARY-TO-SECONDARY STAGNATION PRESSURE       *
C      *           RATIO                                          *
C      *  PM3SO  = MIXED STREAM STATIC-TO-SECONDARY STAGNATION    *
C      *           PRESSURE RATIO                                 *
C      *  FAIL   = ERROR FLAG                                     *
C      *                                                          *
C      ************************************************************
C
C
       SUBROUTINE CAES(GS,GP,MWSP,TSOPO,MS1,MP1,AP1M3,WSP,GM,
      -MWMP,TMOPO,MM3,PPOSO,PM3SO,FAIL)
C
       IMPLICIT REAL*4(M)
       REAL*4 NO
       DATA NO/'NO'/
C
```

7.4.1 CLGDOP (Cont.)

```
C                                                                    CAES   05100
C     ***********************************************************   CAES   05200
C     *                                                         *   CAES   05300
C     *         CALCULATE PS1P1 FOR THE BREAK-OFF POINT.        *   CAES   05400
C     *                                                         *   CAES   05500
C     ***********************************************************   CAES   05600
C                                                                    CAES   05700
C                                                                    CAES   05800
      IF(MS1.NE.1.0) GO TO 100                                       CAES   05900
      PS1P1=1.0                                                      CAES   06000
      GO TO 101                                                      CAES   06100
100   CALL CAEFC(GS,GP,MS1,MF1,AP1M3,PS1P1,FAIL)                     CAES   06200
      IF(FAIL.NE.NO) RETURN                                          CAES   06300
C                                                                    CAES   06400
C                                                                    CAES   06500
C     ***********************************************************   CAES   06600
C     *                                                         *   CAES   06700
C     *  CALCULATE THE DOWNSTREAM CONDITIONS FCR THE BREAK-OFF  *   CAES   06800
C     *  PCINT.                                                 *   CAES   06900
C     *                                                         *   CAES   07000
C     ***********************************************************   CAES   07100
C                                                                    CAES   07200
C                                                                    CAES   07300
101   CALL CAEOCV(GS,GP,MWSP,TSOPO,MS1,MP1,AP1M3,PS1P1,WSP,GM,       CAES   07400
     -MWMP,TMOPO,MM3,PPOSO,PM3SO,FAIL)                               CAES   07500
      END                                                            CAES   07600
```

7.4.1 CLGDOP (Cont.)

```
C     ************************************************************
C     *                                                          *
C     *                  CONSTANT-AREA EJECTOR                   *
C     *          FABRI CRITERION SUBROUTINE (CAEFC)              *
C     *               (OF SUBROUTINE CAES)                       *
C     *                                                          *
C     ************************************************************
C
C     ************************************************************
C     *                                                          *
C     *  SUBROUTINE CAEFC PERFORMS THE CONSTANT-AREA EJECTOR.    *
C     *  FABRI CRITERION CALCULATIONS BY 1-D ANALYSIS FOR A      *
C     *  SUPERSONIC PRIMARY (MP1>1) AND A SUBSONIC SECONDARY     *
C     *  (MS1<1) WHICH CHOKES IN THE EJECTOR SHROUD (MS2=1).     *
C     *  THIS EJECTOR ANALYSIS IS BASED ON THE CONSTANT-AREA     *
C     *  SHROUD, EJECTOR ANALYSIS OF FABRI,  REFERENCE:          *
C     *  NACA TM 1410.                                           *
C     *                                                          *
C     *  INPUT VARIABLES:                                        *
C     *                                                          *
C     *  GS      = SECONDARY GAMMA                               *
C     *  GP      = PRIMARY GAMMA                                 *
C     *  MS1     = SECONDARY MACH NO. AT THE MIXING TUBE         *
C     *              ENTRANCE                                    *
C     *  MP1     = PRIMARY MACH NO. AT THE MIXING TUBE ENTRANCE  *
C     *  AP1M3   = PRIMARY-TO-MIXING TUBE AREA RATIO             *
C     *                                                          *
C     *  OUTPUT VARIABLES:                                       *
C     *                                                          *
C     *  PS1P1   = SECONDARY-TO-PRIMARY STATIC PRESSURE RATIO    *
C     *  FAIL    = ERROR FLAG                                    *
C     *                                                          *
C     ************************************************************
C
C
      SUBROUTINE CAEFC(GS,GP,MS1,MP1,AP1M3,PS1P1,FAIL)
C
      IMPLICIT REAL*4(M)
      DATA YES/'YES'/,PART/'PART'/,SUP/'SUP'/
C
C
C     ************************************************************
C     *                                                          *
C     *                  GAS DYNAMIC FUNCTIONS                   *
C     *                                                          *
C     ************************************************************
C
C
      PPOM(G,M)=(1.+.5*(G-1.)*(M**2))**(-G/(G-1.))
      AASM(G,M)=(1./M)*(((2./(G+1.))*(1.+0.5*(G-1.)*(M**2)))
```

```
     -**(0.5*(G+1.)/(G-1.)))                                          CAEFC
      MMS(G,MS)=SQRT(((2./(G+1.))*(MS**2))/                           CAEFC
     -(1.-((G-1.)/(G+1.))*(MS**2)))                                   CAEFC
C                                                                     CAEFC
C                                                                     CAEFC
C     ****************************************************************CAEFC
C     *                                                              *CAEFC
C     *           FABRI'S CRITERION APPLIES ONLY WHEN                *CAEFC
C     *           (MS1.LE.1.0) AND (PS1P1.LE.1.0).                   *CAEFC
C     *                                                              *CAEFC
C     ****************************************************************CAEFC
C                                                                     CAEFC
C                                                                     CAEFC
      IF(MS1.GT.(1.0)) GO TO 101                                      CAEFC
      IF((1.-MS1).LT.(1.E-4)) GO TO 100                               CAEFC
C                                                                     CAEFC
C                                                                     CAEFC
C     ****************************************************************CAEFC
C     *                                                              *CAEFC
C     *    CALCULATE MP2 AT STATION (2) WHERE MS2=1.0 FROM           *CAEFC
C     *    THE AREA RATIO FOR STREAM (P) AT STATION (2).             *CAEFC
C     *                                                              *CAEFC
C     ****************************************************************CAEFC
C                                                                     CAEFC
C                                                                     CAEFC
      AP2PS=(AASM(GP,MP1)/AP1M3)*(1.-(1.-AP1M3)/AASM(GS,MS1))         CAEFC
      CALL MAAS(GP,MP1,AP2PS,SUP,5.0E-06,MP2,FAIL)                    CAEFC
      IF(FAIL.EQ.YES) GO TO 105                                       CAEFC
      IF(MP2.LT.MP1) GO TO 108                                        CAEFC
      IF((MP2/MP1-1.).LT.(1.E-4)) GO TO 100                           CAEFC
C                                                                     CAEFC
C                                                                     CAEFC
C     ****************************************************************CAEFC
C     *                                                              *CAEFC
C     *            CALCULATE STATIC PRESSURE RATIO                   *CAEFC
C     *            PS1P1 BASED ON FABRI'S CRITERION.                 *CAEFC
C     *                                                              *CAEFC
C     ****************************************************************CAEFC
C                                                                     CAEFC
C                                                                     CAEFC
      VD=(1.0-AP1M3)*((1.0+GS*(MS1**2))-                              CAEFC
     -(PPOM(GS,1.0)/PPOM(GS,MS1))*((1.0+GS)/AASM(GS,MS1)))            CAEFC
      VN=(PPOM(GP,MP2)/PPOM(GP,MP1))*AP1M3*(AASM(GP,MP2)/             CAEFC
     -AASM(GP,MP1))*(1.+GP*(MP2**2))-AP1M3*(1.+GP*(MP1**2))           CAEFC
      PS1P1=VN/VD                                                     CAEFC
      IF(PS1P1.LE.(0.0)) GO TO 103                                    CAEFC
      IF(PS1P1.GT.(1.0)) GO TO 100                                    CAEFC
      RETURN                                                          CAEFC
C                                                                     CAEFC
C                                                                     CAEFC
```

7.4.1 CLGDOP (Cont.)

```
C     ******************************************************         CAEFC  10100
C     *                                                    *         CAEFC  10200
C     *              MS1 IS APPROXIMATELY 1.0 AND          *         CAEFC  10300
C     *              MP1 IS APPROXIMATELY MP1.             *         CAEFC  10400
C     *                                                    *         CAEFC  10500
C     ******************************************************         CAEFC  10600
C                                                                    CAEFC  10700
C                                                                    CAEFC  10800
100   PS1P1=1.0                                                      CAEFC  10900
      RETURN                                                         CAEFC  11000
C                                                                    CAEFC  11100
C                                                                    CAEFC  11200
C     ******************************************************         CAEFC  11300
C     *                                                    *         CAEFC  11400
C     *                   ERROR MESSAGES                   *         CAEFC  11500
C     *                                                    *         CAEFC  11600
C     ******************************************************         CAEFC  11700
C                                                                    CAEFC  11800
C                                                                    CAEFC  11900
101   WRITE(5,102)                                                   CAEFC  12000
102   FORMAT(/,5X,'...ERROR IN CAEFC: (MS1.GT.(1.0)) .',//)          CAEFC  12100
      GO TC 107                                                      CAEFC  12200
103   WRITE(5,104)                                                   CAEFC  12300
104   FORMAT(/,5X,'...ERROR IN CAEFC: (PS1P1.LT.(0.0)).',//)         CAEFC  12400
      GO TC 107                                                      CAEFC  12500
105   WRITE(5,106)                                                   CAEFC  12600
106   FORMAT('0',T2,'SUBROUTINE MAAS WAS CALLED FROM ',              CAEFC  12700
     -'SUBROUTINE CAEFC')                                            CAEFC  12800
107   FAIL=YES                                                       CAEFC  12900
      RETURN                                                         CAEFC  13000
108   FAIL=PART                                                      CAEFC  13100
      END                                                            CAEFC  13200
```

```
C     ***************************************************************
C     *                                                             *
C     *                  CONSTANT-AREA EJECTOR                      *
C     *      OVERALL CONTROL VOLUME SUBROUTINE (CAEOCV)             *
C     *               (OF SUBROUTINE CAES)                          *
C     *                                                             *
C     ***************************************************************
C
C     ***************************************************************
C     *                                                             *
C     *  SUBROUTINE CAEOCV PERFORMS THE CONSTANT-AREA EJECTOR,      *
C     *  OVERALL CONTROL VOLUME CALCULATIONS BY 1-D ANALYSIS        *
C     *  FROM INLET SECTION (1) TO MIXED SECTION (3).               *
C     *                                                             *
C     *  INPUT VARIABLES:                                           *
C     *                                                             *
C     *  GS      = SECONDARY GAMMA                                  *
C     *  GP      = PRIMARY GAMMA                                    *
C     *  MWSP    = SECONDARY-TO-PRIMARY MOLECULAR WEIGHT RATIO      *
C     *  TSOPO   = SECONDARY-TO-PRIMARY STAGNATION TEMPERATURE      *
C     *            RATIO                                            *
C     *  MS1     = SECONDARY MACH NO. AT THE MIXING TUBE            *
C     *            ENTRANCE                                         *
C     *  MP1     = PRIMARY MACH NO. AT THE MIXING TUBE ENTRANCE     *
C     *  AP1M3   = PRIMARY-TO-MIXING TUBE AREA RATIO                *
C     *  PS1P1   = SECONDARY-TO-PRIMARY STATIC PRESSURE RATIO       *
C     *                                                             *
C     *  OUTPUT VARIABLES:                                          *
C     *                                                             *
C     *  WSP     = SECONDARY-TO-PRIMARY MASS FLOW RATIO             *
C     *  GM      = MIXED STREAM GAMMA                               *
C     *  MWMP    = MIXED STREAM-TO-PRIMARY MOLECULAR WEIGHT         *
C     *            RATIO                                            *
C     *  TMOPO   = MIXED STREAM-TO-PRIMARY STAGNATION               *
C     *            TEMPERATURE RATIO                                *
C     *  MM3     = MIXED STREAM MACH NO. AT THE MIXING TUBE         *
C     *            EXIT                                             *
C     *  PPOSO   = PRIMARY-TO-SECONDARY STAGNATION PRESSURE         *
C     *            RATIO                                            *
C     *  PM3SO   = MIXED STREAM STATIC-TO-SECONDARY STAGNATION      *
C     *            PRESSURE RATIO                                   *
C     *  FAIL    = ERROR FLAG                                       *
C     *                                                             *
C     ***************************************************************
C
      SUBROUTINE CAEOCV(GS,GP,MWSP,TSOPO,MS1,MP1,AP1M3,PS1P1,
     -WSP,GM,MWMP,TMOPO,MM3,PPOSO,PM3SO,FAIL)
C
      IMPLICIT REAL*4(M)
```

```
      DATA PART/'PART'/
C
C
C     ************************************************************
C     *                                                          *
C     *                GAS DYNAMIC FUNCTIONS                     *
C     *                                                          *
C     ************************************************************
C
C
      WM(G,M)=M*SQRT(G*(1.+.5*(G-1.)*(M**2)))
      T(G,M)=(1.+G*(M**2))/(M*SQRT(1.+.5*(G-1.)*(M**2)))
      PPOM(G,M)=(1.+.5*(G-1.)*(M**2))**(-G/(G-1.))
C
C
C     ************************************************************
C     *                                                          *
C     *               EJECTOR MASS FLOW RATIO                    *
C     *                                                          *
C     ************************************************************
C
C
      CO=SQRT(MWSP/TSOPO)
      WSP=PS1P1*((1.-AP1M3)/AP1M3)*CO*(WM(GS,MS1)/WM(GP,MP1))
      CPSP=(GS/GP)*((GP-1.)/(GS-1.))/MWSP
C
C
C     ************************************************************
C     *                                                          *
C     *                MIXED FLOW PROPERTIES                     *
C     *                                                          *
C     ************************************************************
C
C
      MWMP=(1.+WSP)/(1.+(WSP/MWSP))
      GM=1./(1.-((GP-1.)/GP)*((1.+(WSP/MWSP))/(1.+CPSP*WSP)))
      TMOPO=(1.+WSP*CPSP*TSOPO)/(1.+WSP*CPSP)
C
C
C     ************************************************************
C     *                                                          *
C     *                    SOLVE FOR MM3                         *
C     *                                                          *
C     ************************************************************
C
C
      C1=SQRT((TSOPO/MWSP)*(GP/GS))
      C2=SQRT(TMOPO/MWMF*(GP/GM))
      TM3=(T(GP,MP1)+C1*WSP*T(GS,MS1))/((1.+WSP)*C2)
      TM3MIN=SQRT(2.*(GM+1.))
```

7.4.1 CLGDOP (Cont.)

```
      IF(TM3.LT.TM3MIN) GO TC 10                                        CAEOCV 10100
      C3=(TM3**2-2.*GM)                                                 CAEOCV 10200
      C4=(((GM-1.)/2.)*(TM3**2)-GM**2)                                  CAEOCV 10300
      C5=SQRT(C3**2+4.*C4)                                              CAEOCV 10400
      MSQD3M=(-C3-C5)/(2.*C4)                                           CAEOCV 10500
      MSQD3P=(-C3+C5)/(2.*C4)                                           CAEOCV 10600
C                                                                       CAEOCV 10700
C                                                                       CAEOCV 10800
C     ***************************************************************** CAEOCV 10900
C     *                                                               * CAEOCV 11000
C     *        DETERMINE TWO POSSIBLE MIXED-FLOW MACH NO.             * CAEOCV 11100
C     *        SOLUTICNS.  USE ONLY SUBSONIC RESULT AT (3).           * CAEOCV 11200
C     *                                                               * CAEOCV 11300
C     ***************************************************************** CAEOCV 11400
C                                                                       CAEOCV 11500
C                                                                       CAEOCV 11600
      IF(MSQD3M.GE.(0.C)) MM3M=SQRT(MSQD3M)                             CAEOCV 11700
      IF(MSQD3P.GE.(0.0)) MM3P=SQRT(MSCD3P)                             CAEOCV 11800
      MM3=MM3P                                                          CAEOCV 11900
C                                                                       CAEOCV 12000
C                                                                       CAEOCV 12100
C     ***************************************************************** CAEOCV 12200
C     *                                                               * CAEOCV 12300
C     *                   CALCULATE PRESSURE RATIOS                   * CAEOCV 12400
C     *                                                               * CAEOCV 12500
C     ***************************************************************** CAEOCV 12600
C                                                                       CAEOCV 12700
C                                                                       CAEOCV 12800
      C6=SQRT(TMOPO/MWMP)                                               CAEOCV 12900
      PM3P1=C6*AP1M3*(1.+WSP)*(WM(GP,MP1)/WM(GM,MM3))                   CAEOCV 13000
      PPOSO=(PPOM(GS,MS1)/PPOM(GP,MP1))/PS1P1                           CAEOCV 13100
      PM3SO=PM3P1*(PPOM(GS,MS1)/PS1P1)                                  CAEOCV 13200
      PMOSO=PM3SO/PPOM(GM,MM3)                                          CAEOCV 13300
      RETURN                                                            CAEOCV 13400
C                                                                       CAEOCV 13500
C                                                                       CAEOCV 13600
C     ***************************************************************** CAEOCV 13700
C     *                                                               * CAEOCV 13800
C     *                        ERROR MESSAGES                         * CAEOCV 13900
C     *                                                               * CAEOCV 14000
C     ***************************************************************** CAEOCV 14100
C                                                                       CAEOCV 14200
C                                                                       CAEOCV 14300
10    FAIL=PART                                                         CAEOCV 14400
      END                                                               CAEOCV 14500
```

```
C      ************************************************************
C      *                                                          *
C      *     SUPERSONIC-SUPERSONIC EJECTOR SUBROUTINE (SSES)      *
C      *                                                          *
C      ************************************************************
C
C      ************************************************************
C      *                                                          *
C      *  SUBROUTINE SSES CALCULATES THE MAXIMUM COMPRESSION      *
C      *  RATIO FOR A CONSTANT-AREA, SUPERSONIC-SUPERSONIC        *
C      *  EJECTOR, BY ONE-DIMENSIONAL ANALYSIS, ASSUMING AN       *
C      *  ISENTROPIC RECOMPRESSION OF THE SECONDARY STREAM TO     *
C      *  SONIC CONDITIONS.                                       *
C      *                                                          *
C      *  INPUT VARIABLES:                                        *
C      *                                                          *
C      *  GS     = SECONDARY GAMMA                                *
C      *  GP     = PRIMARY GAMMA                                  *
C      *  MWSMWP = SECONDARY-TO-PRIMARY MOLECULAR WEIGHT RATIO    *
C      *  TSOTPO = SECONDARY-TO-PRIMARY STAGNATION TEMPERATURE    *
C      *           RATIO                                          *
C      *  MS1    = SECONDARY MACH NO. AT THE MIXING TUBE          *
C      *           ENTRANCE                                       *
C      *  MP1    = PRIMARY MACH NO. AT THE MIXING TUBE ENTRANCE   *
C      *  AS1AP1 = SECONDARY-TO-PRIMARY AREA RATIO                *
C      *                                                          *
C      *  OUTPUT VARIABLES:                                       *
C      *                                                          *
C      *  WSWP   = SECONDARY-TO-PRIMARY MASS FLOW RATIO           *
C      *  GM     = MIXED STREAM GAMMA                             *
C      *  MWMMWP = MIXED STREAM-TO-PRIMARY MOLECULAR WEIGHT       *
C      *           RATIO                                          *
C      *  TMOTPO = MIXED STREAM-TO-PRIMARY STAGNATION             *
C      *           TEMPERATURE RATIO                              *
C      *  MM3    = MIXED STREAM MACH NO. AT THE MIXING TUBE       *
C      *           EXIT                                           *
C      *  PPOPS1 = PRIMARY STAGNATION-TO-SECONDARY STATIC         *
C      *           PRESSURE RATIO                                 *
C      *  PM3PS1 = STATIC PRESSURE COMPRESSION RATIO              *
C      *  FAIL   = ERROR FLAG                                     *
C      *                                                          *
C      ************************************************************
C
C
      SUBROUTINE SSES(GS,GP,MWSMWP,TSOTPO,MS1,MP1,AS1AP1,WSWP,
     -GM,MWMMWP,TMOTPO,MM3,PPOPS1,PM3PS1,FAIL)
C
      IMPLICIT REAL*4(M)
      DATA YES/'YES'/,SUP/'SUP'/
C
```

7.4.1 CGLDOP (Cont.)

```
C
C     ************************************************************
C     *                                                          *
C     *                  SPECIAL FUNCTIONS                       *
C     *                                                          *
C     ************************************************************
C
C
      F(GX,MXX)=1.0+GX*MXX*MXX
      G(GX,MXX)=MXX*SQRT(1.0+0.5*(GX-1.0)*MXX*MXX)
      H(MM,TT,GG)=SQRT(MM*GG/TT)
      PPO(GX,MXX)=(1.0+0.5*(GX-1.0)*MXX*MXX)**(GX/(1.0-GX))
      AAS(GX,MXX)=((2.0*(1.0+0.5*(GX-1.0)*MXX*MXX)/(GX+1.0))**(0.5*(GX+1
     -.0)/(GX-1.0)))/MXX
C
C
C     ************************************************************
C     *                                                          *
C     *                 CALCULATE CONSTANTS                      *
C     *                                                          *
C     ************************************************************
C
C
      GS3=GS/(GS-1.0)
      GP3=GP/(GP-1.0)
      GSGP=GS/GP
      MWPMWS=1.0/MWSMWP
      PP1PP0=PPO(GP,MP1)
      AS1ASS=AAS(GS,MS1)
      AP1APS=AAS(GP,MP1)
      ASSAS1=1.0/AS1ASS
      FGSMS1=F(GS,MS1)
      FGPMP1=F(GP,MP1)
      GGSMS1=G(GS,MS1)
      GGPMP1=G(GP,MP1)
C
C
C     ************************************************************
C     *                                                          *
C     *  CALCULATE FS1PP1 FOR AN ISENTROPIC RECOMPRESSION TO     *
C     *  SONIC CONDITIONS.  MP2 IS OBTAINED FROM AP2APS.          *
C     *                                                          *
C     ************************************************************
C
C
      IF(AS1AP1.GE.0.0) GO TO 1
      WRITE(5,2)AS1AP1
      FAIL=YES
      RETURN
1     AP2APS=AP1APS*(1.0+AS1AP1*(1.0-ASSAS1))
```

7.4.1 CGLDOP (Cont.)

```
      CALL MAAS(GP,MP1,AP2APS,SUP,5.0E-06,MP2,FAIL)
      IF(FAIL.EQ.YES) RETURN
      MS2=1.0
      C1=-FGPMP1+F(GP,MP2)*GGPMP1/G(GP,MP2)
      C2=FGSMS1-F(GS,MS2)*GGSMS1/G(GS,MS2)
      PS1PP1=C1/(AS1AP1*C2)
C
C     ************************************************************
C     *                                                          *
C     *          OVERALL CONTROL VOLUME CALCULATIONS             *
C     *                                                          *
C     ************************************************************
C
      WSWP=PS1PP1*AS1AP1*H(MWSMWP,TSOTP0,GSGP)*GGSMS1/GGPMP1
      C1=WSWP*MWPMWS*GS3+GP3
      C2=WSWP*MWPMWS*(GS3-1.0)+(GP3-1.0)
      GM=C1/C2
      GMGP=GM/GP
      MWMMWP=(WSWP+1.0)/(WSWP*MWPMWS+1.0)
      C1=TSOTP0*WSWP*MWPMWS*GS3+GP3
      C2=WSWP*MWPMWS*GS3+GP3
      TMOTP0=C1/C2
      FFX=H(MWMMWP,TMOTP0,GMGP)*(PS1PP1*AS1AP1*FGSMS1+FGPMP1)/(
     -(1.0+WSWP)*GGPMP1)
      C1=0.5*(GM-1.0)*FFX*FFX-GM*GM
      C2=FFX*FFX-2.0*GM
      C3=(-C2+SQRT(C2*C2+4.0*C1))/(2.0*C1)
      C4=(-C2-SQRT(C2*C2+4.0*C1))/(2.0*C1)
      MM3=SQRT(AMIN1(C3,C4))
      PM3PP1=(PS1PP1*AS1AP1*FGSMS1+FGPMP1)/((1.0+AS1AP1)*F(GM,MM3))
      PM3PS1=PM3PP1/PS1PP1
      PS1PP0=PS1PP1*PP1PP0
      PP0PS1=1.0/PS1PP0
C
C     ************************************************************
C     *                                                          *
C     *                  FORMAT STATEMENTS                       *
C     *                                                          *
C     ************************************************************
C
C
2     FORMAT('0',T2,'IMPOSSIBLE VALUE...AS1AP1 =',E13.6)
      END
```

7.4.1 CGLDOP (Cont.)

```
C     ************************************************************
C     *                                                          *
C     *              MINIMIZATION SUBROUTINE (MIN)               *
C     *                                                          *
C     ************************************************************
C
C     ************************************************************
C     *                                                          *
C     *  SUBROUTINE MIN, AS APPLIED TO A CONSTANT-AREA           *
C     *  SUBSONIC-SUPERSONIC EJECTOR, PERFORMS A SEARCH AND      *
C     *  INTERVAL HALVING PROCEDURE TO FIND MS1 SUCH THAT        *
C     *  FUNC(MS1) IS A MINIMUM.                                 *
C     *                                                          *
C     *  VARIABLES:                                              *
C     *                                                          *
C     *  MS1     = SECONDARY MACH NO. AT THE MIXING TUBE         *
C     *            ENTRANCE                                      *
C     *  FUNC    = FUNCTION OF MS1                               *
C     *  NTYPE   = 1,2 - SEARCH                                  *
C     *          = 3,4 - SOLUTION                                *
C     *  NIT     = INCREMENT NUMBER                              *
C     *  COEFF   = ALPHANUMERIC IMAGE OF FUNC                    *
C     *  FAIL    = ERROR FLAG                                    *
C     *                                                          *
C     ************************************************************
C
      SUBROUTINE MIN(MS1,FUNC,NTYPE,NIT,COEFF,FAIL)
C
      IMPLICIT REAL*4(M)
      REAL*4 NO
      DATA DX,XLOW,XERROR,YERROR/0.1,1.0E-03,0.025,1.0/
      DATA YES/'YES'/,NO/'NO'/,PART/'PART'/
C
      ERROR(ACTUAL,GIVEN)=(ACTUAL-GIVEN)*100.0/GIVEN
C
C
C     ************************************************************
C     *                                                          *
C     *    NO CAE SOLUTION EXITS FOR CURRENT VALUE OF MS1.       *
C     *    INCREMENT MS1 AND SEARCH FOR SOLUTION.                *
C     *                                                          *
C     ************************************************************
C
C
      IF(FAIL.NE.PART) GO TO 100
      MS1=MS1-XERROR
      IF(MS1.LT.XLOW) GO TO 108
      FAIL=NO
      RETURN
```

```
100   IF(NIT.NE.1) GO TO 101                                          MIN   05100
      WRITE(5,200)COEFF                                               MIN   05200
      DMS1=DX                                                         MIN   05300
      MS1LCW=XLCW                                                     MIN   05400
101   WRITE(5,201)NTYPE,MS1,FUNC,DMS1,FAIL                            MIN   05500
      NIT=NIT+1                                                       MIN   05600
      GO TO (102,104,107),NTYPE                                       MIN   05700
C                                                                     MIN   05800
C                                                                     MIN   05900
C     **********************************************************      MIN   06000
C     *                                                        *      MIN   06100
C     *                STORE UPPER BOUND FOR MS1               *      MIN   06200
C     *                                                        *      MIN   06300
C     **********************************************************      MIN   06400
C                                                                     MIN   06500
C                                                                     MIN   06600
102   X1=MS1                                                          MIN   06700
      Y1=FUNC                                                         MIN   06800
103   MS1=MS1-DMS1                                                    MIN   06900
      IF(MS1.LT.MS1LCW) GO TO 108                                     MIN   07000
      NTYPE=2                                                         MIN   07100
      RETURN                                                          MIN   07200
C                                                                     MIN   07300
C                                                                     MIN   07400
C     **********************************************************      MIN   07500
C     *                                                        *      MIN   07600
C     *                STORE LOWER BOUND FOR MS1               *      MIN   07700
C     *                                                        *      MIN   07800
C     **********************************************************      MIN   07900
C                                                                     MIN   08000
C                                                                     MIN   08100
104   X2=MS1                                                          MIN   08200
      Y2=FUNC                                                         MIN   08300
      IF(Y2.GT.Y1) GO TO 105                                          MIN   08400
      GO TO 102                                                       MIN   08500
C                                                                     MIN   08600
C                                                                     MIN   08700
C     **********************************************************      MIN   08800
C     *                                                        *      MIN   08900
C     *        TEST FUNC FOR MINIMUM AND INTERVAL HALVE        *      MIN   09000
C     *                                                        *      MIN   09100
C     **********************************************************      MIN   09200
C                                                                     MIN   09300
C                                                                     MIN   09400
105   IF(ABS(ERROR(Y2,Y1)).LE.YERROR) GO TO 106                       MIN   09500
      DMS1=DMS1/2.0                                                   MIN   09600
      IF(DMS1.LT.XERROR) GO TO 106                                    MIN   09700
      MS1LCW=X2                                                       MIN   09800
      MS1=X1                                                          MIN   09900
      GO TO 103                                                       MIN   10000
```

7.4.1 CGLDOP (Cont.)

```
C
C
C      ***************************************************
C      *                                                 *
C      *  MS1 FOR MIN FUNC HAS BEEN FOUND BUT SOLUTION WAS LOST *
C      *                                                 *
C      ***************************************************
C
C
106    IF(Y2.LE.Y1) GO TO 107
       MS1=X1
       NTYPE=3
       RETURN
C
C
C      ***************************************************
C      *                                                 *
C      *   MS1 FOR MIN FUNC HAS BEEN FOUND AND SOLUTION SAVED   *
C      *                                                 *
C      ***************************************************
C
C
107    NTYPE=4
       RETURN
C
C
C      ***************************************************
C      *                                                 *
C      *          SEARCH FAILLRE: NO CAE SOLUTICN FOUND          *
C      *                                                 *
C      ***************************************************
C
C
108    WRI  (5,202)MS1,MSILCW,DMS1
       FAIL YES
C
C
C      ***************************************************
C      *                                                 *
C      *                     FORMAT STATEMENTS                   *
C      *                                                 *
C      ***************************************************
C
C
200    FORMAT('1',T30,'SEARCH DATA:',//,T8,'NTYPE',T21,'MS1',
      -T35,A5,T5C,'DMS1',T60,'FAIL',/)
201    FORMAT(' ',T10,I1,T13,3E15.6,T60,A4)
202    FORMAT('0',T2,'MS1 =',E13.6,2X,'BELOW LOWER LIMIT MS1 =',
      -E13.6,/,T2,'FCR DMS1 =',E13.6)
       END
```

```
C      ************************************************************
C      *                                                          *
C      *                  SUBROUTINE (MAAS)                       *
C      *                                                          *
C      ************************************************************
C
C      ************************************************************
C      *                                                          *
C      *  SUBROUTINE MAAS CALCULATES THE MACH NUMBER (M) GIVEN   *
C      *  THE AREA RATIO (A/A*) BY LINEAR ITERATION.              *
C      *                                                          *
C      *  INPUT VARIABLES:                                        *
C      *                                                          *
C      *  G       = SPECIFIC HEAT RATIO                           *
C      *  MINI    = INITIAL VALUE OF MACH NUMBER                  *
C      *  AAS     = THE AREA RATIO A/A*                           *
C      *  FLOW    = CONTROL VARIABLE SUCH THAT                    *
C      *          = "SUB" FOR THE SUBSONIC BRANCH                 *
C      *          = "SUP" FOR THE SUPERSONIC BRANCH               *
C      *  ERROR   = MAX PERCENT DEVIATION IN MOLD AND MNEW FOR   *
C      *            A SOLUTION                                    *
C      *                                                          *
C      *  OUTPUT VARIABLES:                                       *
C      *                                                          *
C      *  MNEW    = FINAL VALUE OF MACH NUMBER                    *
C      *  FAIL    = ERROR FLAG                                    *
C      *                                                          *
C      ************************************************************
C
C
       SUBROUTINE MAAS(G,MINI,AAS,FLOW,ERROR,MNEW,FAIL)
C
       IMPLICIT REAL*4(M)
       DATA YES/'YES'/,SUP/'SUP'/
C
C
C      ************************************************************
C      *                                                          *
C      *                 CALCULATE CONSTANTS                      *
C      *                                                          *
C      ************************************************************
C
C
       G1=(G-1.0)/2.0
       G1I=1.0/G1
       G2=2.0/(G+1.0)
       G2I=1.0/G2
       G4=(G+1.0)/(2.0*(G-1.0))
       G4I=1.0/G4
C
```

7.4.1 CGLDOP (Cont.)

```
C
C     ***********************************************************
C     *                                                         *
C     *              CALCULATE THE SUPERSONIC BRANCH            *
C     *                                                         *
C     ***********************************************************
C
C
      MOLD=MINI
      IF(FLOW.NE.SUP) GO TO 2
      DO 1 J=1,200
      C1=(MOLD*AAS)**G4I
      MNEW=SQRT(G1I*(G2I*C1-1.0))
      XERROR=(MNEW-MOLD)*100.0/MOLD
      MOLD=MNEW
      IF(ABS(XERROR).LT.ERROR) RETURN
1     CONTINUE
      GO TO 4
C
C
C     ***********************************************************
C     *                                                         *
C     *              CALCULATE THE SUBSONIC BRANCH              *
C     *                                                         *
C     ***********************************************************
C
C
2     DO 3 J=1,200
      C1=1.0+G1*MOLD*MOLD
      MNEW=((G2*C1)**G4)/AAS
      XERROR=(MNEW-MOLD)*100.0/MOLD
      MOLD=MNEW
      IF(ABS(XERROR).LT.ERROR) RETURN
3     CONTINUE
C
C
C     ***********************************************************
C     *                                                         *
C     *                  CONVERGENCE FAILURE                    *
C     *                                                         *
C     ***********************************************************
C
C
4     WRITE(5,5)FLOW,G,MINI,MNEW,AAS,XERROR,ERROR
      FAIL=YES
5     FORMAT('0',T2,'CONVERGENCE FAILURE FOR ',A3,'SONIC ',
     -'BRANCH IN SUBROUTINE MAAS',/,
     -T2,'G      =',E13.6,2X,'MINI     =',E13.6,/,
     -T2,'MNEW   =',E13.6,2X,'AAS      =',E13.6,/,
     -T2,'XERROR =',E13.6,2X,'ERROR    =',E13.6)
```

7.4.1 CGLDOP (Cont.)

```
MAAS 10100

END
```

```
C     *****************************************************************  ITER   00100
C     *                                                               *  ITER   00200
C     *                  ITERATION SUBROUTINE (ITER)                  *  ITER   00300
C     *                                                               *  ITER   00400
C     *****************************************************************  ITER   00500
C                                                                        ITER   00600
C     *****************************************************************  ITER   00700
C     *                                                               *  ITER   00800
C     *  SUBROUTINE ITER PERFORMS AN ITERATICN TO FIND X SUCH         *  ITER   00900
C     *  THAT THE PERCENT ERROR IN Y AND YGIVEN IS .LE. TO            *  ITER   01000
C     *  ERRORY OR THE PERCENT DEVIATION IN X(I+1) AND X(I)           *  ITER   01100
C     *  IS .LE. TO ERRORX.                                           *  ITER   01200
C     *                                                               *  ITER   01300
C     * VARIABLES:                                                    *  ITER   01400
C     *                                                               *  ITER   01500
C     * X      = INDEPENDENT VARIABLE                                 *  ITER   01600
C     * DX     = INCREMENT IN INDEPENDENT VARIABLE                    *  ITER   01700
C     * ERRORX = MAX PERCENT DEVIATION IF X(I+1) AND X(I) FOR         *  ITER   01800
C     *          SOLUTICN                                             *  ITER   01900
C     * SIGN   = +1.0 OR -1.0, +/- INCREMENTING FROM INITIAL X        *  ITER   02000
C     * Y      = DEPENDENT VARIABLE                                   *  ITER   02100
C     * YGIVEN = GIVEN VALUE OF DEPENDENT VARIABLE                    *  ITER   02200
C     * ERRORY = MAX PERCENT ERROR IN Y AND YGIVEN FOR                *  ITER   02300
C     *          SOLUTICN                                             *  ITER   02400
C     * NIT    = INCREMENT NUMBER                                     *  ITER   02500
C     * NTYPE  = 1--INCREMENT,  2--INTERPOLATION,  3--SOLUTION        *  ITER   02600
C     *                                                               *  ITER   02700
C     * NOTE: THE INTERMEDIATE VARIABLES XNEG,YNEG,XPOS,YPOS,         *  ITER   02800
C     * NSIGN1,NSIGN2 MUST BE STORED BETWEEN INTERATIONS.             *  ITER   02900
C     *                                                               *  ITER   03000
C     *****************************************************************  ITER   03100
C                                                                        ITER   03200
C                                                                        ITER   03300
      SUBROUTINE ITER(X,DX,ERRORX,SIGN,Y,YGIVEN,ERRORY,NIT,              ITER   03400
     -NTYPE,XNEG,YNEG,XPOS,YPOS,NSIGN1,NSIGN2)                           ITER   03500
C                                                                        ITER   03600
      ERROR(ACTUAL,GIVEN)=(ACTUAL-GIVEN)*100.0/GIVEN                     ITER   03700
C                                                                        ITER   03800
      IF(ABS(ERROR(Y,YGIVEN))-ERRORY) 90,90,10                           ITER   03900
   10 IF(Y-YGIVEN) 20,90,30                                              ITER   04000
   20 NSIGN2=-1                                                          ITER   04100
      XNEG=X                                                             ITER   04200
      YNEG=Y                                                             ITER   04300
      GO TO 40                                                           ITER   04400
   30 NSIGN2=+1                                                          ITER   04500
      XPOS=X                                                             ITER   04600
      YPOS=Y                                                             ITER   04700
   40 GO TO (50,80), NTYPE                                               ITER   04800
   50 IF(NIT-1) 70,70,60                                                 ITER   04900
   60 NSIGN=NSIGN1*NSIGN2                                                ITER   05000
```

7.4.1 CGLDOP (Cont.)

```
      IF(NSIGN) 80,80,70
   70 NSIGN1=NSIGN2
      NIT=NIT+1
C
C     ***************************************************************
C     *                                                             *
C     *            INCREMENT TO FIND SOLUTION INTERVAL              *
C     *                                                             *
C     ***************************************************************
C
C
      X=X+SIGN*DX
      GO TO 100
C
C     ***************************************************************
C     *                                                             *
C     *                 INTERPOLATION FOR SOLUTION                  *
C     *                                                             *
C     ***************************************************************
C
C
   80 NTYPE=2
      NIT=NIT+1
      XSAVE=X
      RATIO=(XPOS-XNEG)/(YPOS-YNEG)
      X=XNEG+RATIO*(YGIVEN-YNEG)
C
C     ***************************************************************
C     *                                                             *
C     *           ACCELERATION OF CONVERGENCE OF ITERATION          *
C     *                  REFERENCE - WEGSTEIN, NBS                  *
C     *                                                             *
C     ***************************************************************
C
C
      A=1.0/RATIO
      IF(A-1.0) 82,88,82
   82 Q=A/(A-1.0)
      XWGSTN=Q*XSAVE+(1.0-Q)*X
      IF(XNEG-XWGSTN) 84,86,88
   84 IF(XWGSTN-XPOS) 86,86,88
   86 X=XWGSTN
   88 IF(ABS(ERROR(X,XSAVE))-ERRORX) 90,90,100
   90 NTYPE=3
  100 END
```

7.4.1 CGLDOP (Cont.)

```
C     ****************************************************************
C     *                                                              *
C     *                    SUBROUTINE (TTY)                          *
C     *                                                              *
C     ****************************************************************
C
C     ****************************************************************
C     *                                                              *
C     *  SUBROUTINE TTY PRINTS THE RESULTS OF PROGRAM CLGDOP         *
C     *  ON TERMINALS WITH A MINIMUM OF 72 CHARACTERS PER            *
C     *  LINE.  SEE MAIN PROGRAM CLGDOP FOR NOTATION.                *
C     *                                                              *
C     ****************************************************************
C
C
      SUBROUTINE TTY
C
      IMPLICIT REAL*4(M)
      DATA CAE/'CAE'/,SSE/'SSE'/
C
      COMMON/TTY1/A2A1,A3A1,A4A1,A4A3,A5A1,A5A6,A6A1,A7A1,A7A2,
     -A7A6,A8A1,A8A7
      COMMON/TTY2/COEFF,CQ1,CQ2,EJECT,GM,GP,GS
      COMMON/TTY3/M1,M2,M3,M4,M5,M6,M7,M8,MWMMWS,MWPMWS,NPTS
      COMMON/TTY4/P1P10,P2P1,P20P10,P3P1,P3CP10,P3P2,P30P20,
     -P4P1,P4CP10,P4P3,P40P30,P5P1,P50P10,P60P1,P60P10,P60P2,
     -P60P20,P6CP50,P7P1,P70P10,P7P2,P70P20,P7P50,P70P50,P8P1,
     -P80P10,P8P2,P80P20,P8P7,P80P70
      COMMON/TTY5/RNSC,RSD34,RSD78
      COMMON/TTY6/T1T10,T2T1,T20T10,T3T1,T30T10,T3T2,T30T20,
     -T4T1,T40T10,T4T3,T40T30,T5T1,T5CT10,T6CT1,T60T10,T60T20,
     -T60T50,T7T1,T7CT10,T7T2,T70T2C,T7T5C,T70T50,T8T1,
     -T80T10,T8T2,T8CT20,T8T7,T80T70
      COMMON/TTY7/WMWS,WPWS
C
C
C     ****************************************************************
C     *                                                              *
C     *                  CUTPUT SYSTEM DATA                          *
C     *                                                              *
C     ****************************************************************
C
C
      WRITE(5,2CC)
      WRITE(5,2C1)EJECT,COEFF
C
      WRITE(5,2C2)
      WRITE(5,2C3)
      WRITE(5,2C4)M1,GS,P1P1C,T1T10
C
```

```
      WRITE(5,205)
      IF(EJECT.EQ.CAE) WRITE(5,206)
      IF(EJECT.EQ.SSE) WRITE(5,207)
      WRITE(5,208)GS,M2,A2A1,P2P1,T2T1,P20P10,T20T10
C
      IF(EJECT.EQ.SSE) GO TO 100
      WRITE(5,209)
      WRITE(5,210)GS,M3,A3A1,P3P1,T3T1,P30P10,T30T10
C
      WRITE(5,211)
      WRITE(5,212)GS,M4,A4A1,P4P1,T4T1,P40P10,T40T10
C
      WRITE(5,213)
      WRITE(5,214)GS,M5,A5A1,P5P1,T5T1,P50P10,T50T10
C
      WRITE(5,215)
      GO TO 101
100   WRITE(5,216)
101   WRITE(5,217)GP,MWPMWS,WPWS,M6,A6A1,P60P1,T60T1,P60P10,
     -T60T10
C
      IF(EJECT.EQ.CAE) WRITE(5,218)
      IF(EJECT.EQ.SSE) WRITE(5,219)
      WRITE(5,220)GM,MWMMWS,WMWS,M7,A7A1,P7P1,T7T1,P70P10,T70T10
C
      WRITE(5,221)
      WRITE(5,222)GM,MWMMWS,WMWS,M8,A8A1,P8P1,T8T1,P80P10,
     -T80T10
C
C
C     ************************************************************
C     *                                                          *
C     *                 OUTPUT DATA FOR EACH DEVICE              *
C     *                                                          *
C     ************************************************************
C
C
      WRITE(5,300)
      WRITE(5,301)NPTS,CQ1,CQ2,GS,A2A1,M1,M2,P2P1,T2T1,P20P10,
     -T20T10
C
      IF(EJECT.EQ.SSE) GO TO 102
      WRITE(5,302)
      WRITE(5,303)GS,RNSD,M2,M3,P3P2,T3T2,P30P20,T30T20
C
      WRITE(5,304)
      WRITE(5,305)RSD34,GS,A4A3,M3,M4,P4P3,T4T3,P40P30,T40T30
C
      WRITE(5,306)
      WRITE(5,307)GS,GP,GM,MWPMWS,A7A6,WPWS,M6,M7,P60P50,T60T50,
```

7.4.1 CGLDOP (Cont.)

```
     -P7P50,T7T50,P7CP50,T7CT50
C
      WRITE(5,3C8)
      WRITE(5,3C9)
      GO TO 103
102   WRITE(5,310)
103   WRITE(5,311)GS,GP,GM,MWPMWS,A7A2,A7A6,WPWS,M2,M6,M7,P6CP2,
     -P60P20,T60T20,P7F2,T7T2,P70P20,T70T2C
C
      IF(EJECT.EC.CAE) WRITE(5,312)
      IF(EJECT.EQ.SSE) WRITE(5,313)
      WRITE(5,314)GS,GP,GM,MWPMWS,A7A2,A7A6,A8A7,WPWS,M2,M6,M7,
     -M8,P60P2,P60P2C,T60T20,P8P2,T8T2,P80P2C,T80T20
C
      WRITE(5,315)
      WRITE(5,316)RSD78,GM,A8A7,M7,M8,P8P7,T8T7,P80P70,T80T70
C
C
C     ***************************************************************
C     *                                                             *
C     *                      FORMAT STATEMENTS                      *
C     *                                                             *
C     ***************************************************************
C
C
200   FORMAT('1',T14,'HIGH ENERGY CHEMICAL LASER SYSTEM ',
     -'SIMULATICN',/,T24,'CNE-DIMENSIONAL ANALYSIS',//,T29,
     -'A.L. ADDY',/,T29,'C.D. MIKKELSEN',/,T29,'M.R. SANDBERG',
     -//,T30,'1 JANUARY 76',//,T19,'MECHANICAL ENGINEERING ',
     -'DEPARTMENT',/,T15,'UNIVERSITY OF ILLINCIS AT URBANA-',
     -'CHAMPAIGN',/,T25,'URBANA, ILLINCIS 61801')
201   FORMAT('0',T20,A3,' SCLUTION FOR MINIMUM ',A5)
C
202   FORMAT('0',T14,'SYSTEM DATA:')
203   FORMAT('0',T5,'PCINT 1  LASER CAVITY ENTRANCE CONDITIONS')
204   FORMAT('0',T14,'M1      =',E13.6,T38,'GS      =',E13.6,/,
     -T14,'P1P10  =',E13.6,T38,'T1T10  =',E13.6)
C
205   FORMAT('0',T5,'POINT 2  LASER CAVITY EXIT AND')
206   FORMAT('+',T36,'NORMAL SHOCK DIFFUSER',/,T14,'ENTRANCE ',
     -'CCNDITICNS')
207   FORMAT('+',T36,'SUPERSCNIC-SUPERSONIC',/,T14,'EJECTOR ',
     -'ENTRANCE CONDITICNS')
208   FORMAT('0',T14,'GS      =',E13.6,/,
     -T14,'M2      =',E13.6,T38,'A2A1    =',E13.6,/,
     -T14,'P2P1    =',E13.6,T38,'T2T1    =',E13.6,/,
     -T14,'P20P10 =',E13.6,T38,'T20T10 =',E13.6)
C
209   FORMAT('C',T5,'POINT 3  NORMAL SHCCK DIFFUSER EXIT AND ',
     -'SUBSONIC',/,T14,'DIFFUSER ENTRANCE CONDITIONS')
```

```
210   FORMAT('0',T14,'GS       =',E13.6,/,
     -T14,'M3      =',E13.6,T38,'A3A1    =',E13.6,/,
     -T14,'P3P1    =',E13.6,T38,'T3T1    =',E13.6,/,
     -T14,'P30P10 =',E13.6,T38,'T30T10 =',E13.6)
C
211   FORMAT('0',T5,'POINT 4  SUBSONIC DIFFUSER EXIT AND ',
     -'SUDDEN ENLARGEMENT',/,T14,'ENTRANCE CONDITIONS')
212   FORMAT('0',T14,'GS       =',E13.6,/,
     -T14,'M4      =',E13.6,T38,'A4A1    =',E13.6,/,
     -T14,'P4P1    =',E13.6,T38,'T4T1    =',E13.6,/,
     -T14,'P40P10 =',E13.6,T38,'T40T10 =',E13.6)
C
213   FORMAT('0',T5,'POINT 5  CONSTANT-AREA EJECTOR SECONDARY ',
     -'NOZZLE EXIT',/,T14,'CONDITIONS')
214   FORMAT('0',T14,'GS       =',E13.6,/,
     -T14,'M5      =',E13.6,T38,'A5A1    =',E13.6,/,
     -T14,'P5P1    =',E13.6,T38,'T5T1    =',E13.6,/,
     -T14,'P50P10 =',E13.6,T38,'T50T10 =',E13.6)
C
215   FORMAT('0',T5,'POINT 6  CONSTANT-AREA EJECTOR PRIMARY ',
     -'NOZZLE EXIT',/,T14,'CONDITIONS')
216   FORMAT('0',T5,'POINT 6  SUPERSONIC-SUPERSONIC EJECTOR ',
     -'PRIMARY NOZZLE',/,T14,'EXIT CONDITIONS')
217   FORMAT('0',T14,'GP       =',E13.6,T38,'MWPMWS =',E13.6,/,
     -T14,'WPWS    =',E13.6,/,
     -T14,'M6      =',E13.6,T38,'A6A1    =',E13.6,/,
     -T14,'P60P1   =',E13.6,T38,'T60T1   =',E13.6,/,
     -T14,'P60P10 =',E13.6,T38,'T60T10 =',E13.6)
C
218   FORMAT('0',T5,'POINT 7  CONSTANT-AREA EJECTOR EXIT AND ',
     -'SUBSONIC',/,T14,'DIFFUSER ENTRANCE CONDITIONS')
219   FORMAT('0',T5,'POINT 7  SUPERSONIC-SUPERSONIC EJECTOR ',
     -'EXIT AND',/,T14,'SUBSONIC DIFFUSER ENTRANCE CONDITIONS')
220   FORMAT('0',T14,'GM       =',E13.6,T38,'MWMMWS =',E13.6,/,
     -T14,'WMWS    =',E13.6,/,
     -T14,'M7      =',E13.6,T38,'A7A1    =',E13.6,/,
     -T14,'P7P1    =',E13.6,T38,'T7T1    =',E13.6,/,
     -T14,'P70P10 =',E13.6,T38,'T70T10 =',E13.6)
C
221   FORMAT('0',T5,'POINT 8  SUBSONIC DIFFUSER EXIT ',
     -'CONDITIONS')
222   FORMAT('0',T14,'GM       =',E13.6,T38,'MWMMWS =',E13.6,/,
     -T14,'WMWS    =',E13.6,/,
     -T14,'M8      =',E13.6,T38,'A8A1    =',E13.6,/,
     -T14,'P8P1    =',E13.6,T38,'T8T1    =',E13.6,/,
     -T14,'P80P10 =',E13.6,T38,'T80T10 =',E13.6)
C
300   FORMAT('0',T14,'LASER CAVITY DATA:')
301   FORMAT('0',T14,'NPTS    =',I13,/,
     -T14,'CQ1     =',E13.6,T38,'CQ2     =',E13.6,/,
```

```
     -T14,'GS       =',E13.6,T38,'A2A1     =',E13.6,/,                 TTY
     -T14,'M1       =',E13.6,T38,'M2       =',E13.6,/,                 TTY
     -T14,'P2P1     =',E13.6,T38,'T2T1     =',E13.6,/,                 TTY
     -T14,'P20P10 =',E13.6,T38,'T20T10 =',E13.6)                       TTY
C                                                                      TTY
302   FORMAT('0',T14,'NORMAL SHOCK DIFFUSER DATA:')                    TTY
303   FORMAT('0',T14,'GS       =',E13.6,T38,'RNSD     =',E13.6,/,      TTY
     -T14,'M2       =',E13.6,T38,'M3       =',E13.6,/,                 TTY
     -T14,'P3P2     =',E13.6,T38,'T3T2     =',E13.6,/,                 TTY
     -T14,'P30P20 =',E13.6,T38,'T30T20 =',E13.6)                       TTY
C                                                                      TTY
304   FORMAT('0',T14,'SUBSONIC DIFFUSER DATA:')                        TTY
305   FORMAT('0',T14,'RSD      =',E13.6,/,                             TTY
     -T14,'GS       =',E13.6,T38,'A4A3     =',E13.6,/,                 TTY
     -T14,'M3       =',E13.6,T38,'M4       =',E13.6,/,                 TTY
     -T14,'P4P3     =',E13.6,T38,'T4T3     =',E13.6,/,                 TTY
     -T14,'P40P30 =',E13.6,T38,'T40T30 =',E13.6)                       TTY
C                                                                      TTY
306   FORMAT('0',T14,'CONSTANT-AREA EJECTOR DATA:')                    TTY
307   FORMAT('0',T14,'GS       =',E13.6,T38,'GP       =',E13.6,/,      TTY
     -T14,'GM       =',E13.6,T38,'MWPMWS =',E13.6,/,                   TTY
     -T14,'A7A6     =',E13.6,T38,'WPWS     =',E13.6,/,                 TTY
     -T14,'M6       =',E13.6,T38,'M7       =',E13.6,/,                 TTY
     -T14,'P60P50 =',E13.6,T38,'T60T50 =',E13.6,/,                     TTY
     -T14,'P7P5C    =',E13.6,T38,'T7T50    =',E13.6,/,                 TTY
     -T14,'P70P50 =',E13.6,T38,'T70T50 =',E13.6)                       TTY
C                                                                      TTY
308   FORMAT('0',T14,'NORMAL SHOCK DIFFUSER - SUBSONIC ',              TTY
     -'DIFFUSER -')                                                    TTY
309   FORMAT(' ',T14,'CONSTANT-AREA EJECTOR DATA:')                    TTY
310   FORMAT('0',T14,'SUPERSONIC-SUPERSONIC EJECTOR DATA:')            TTY
311   FORMAT('0',T14,'GS       =',E13.6,T38,'GP       =',E13.6,/,      TTY
     -T14,'GM       =',E13.6,T38,'MWPMWS =',E13.6,/,                   TTY
     -T14,'A7A2     =',E13.6,T38,'A7A6     =',E13.6,/,                 TTY
     -T14,'WPWS     =',E13.6,T38,'M2       =',E13.6,/,                 TTY
     -T14,'M6       =',E13.6,T38,'M7       =',E13.6,/,                 TTY
     -T14,'P60P2    =',E13.6,/,                                        TTY
     -T14,'P60P20 =',E13.6,T38,'T60T20 =',E13.6,/,                     TTY
     -T14,'P7P2     =',E13.6,T38,'T7T2     =',E13.6,/,                 TTY
     -T14,'P70P20 =',E13.6,T38,'T70T20 =',E13.6)                       TTY
C                                                                      TTY
312   FORMAT('0',T14,'NORMAL SHOCK DIFFUSER - SUBSONIC ',              TTY
     -'DIFFUSER -',/,T14,'CONSTANT-AREA EJECTOR - SUBSONIC ',          TTY
     -'DIFFUSER',/,T14,'DATA:')                                        TTY
313   FORMAT('0',T14,'SUPERSONIC-SUPERSONIC EJECTOR - SUBSONIC',       TTY
     -/,T14,'DIFFUSER DATA:')                                          TTY
314   FORMAT('0',T14,'GS       =',E13.6,T38,'GP       =',E13.6,/,      TTY
     -T14,'GM       =',E13.6,T38,'MWPMWS =',E13.6,/,                   TTY
     -T14,'A7A2     =',E13.6,T38,'A7A6     =',E13.6,/,                 TTY
     -T14,'A8A7     =',E13.6,T38,'WPWS     =',E13.6,/,                 TTY
```

7.4.1 CGLDOP (Cont.)

```
     -T14,'M2      =',E13.6,T38,'M6      =',E13.6,/,                TTY    25100
     -T14,'M7      =',E13.6,T38,'M8      =',E13.6,/,                TTY    25200
     -T14,'P60P2   =',E13.6,/,                                      TTY    25300
     -T14,'P60P20  =',E13.6,T38,'T60T20  =',E13.6,/,                TTY    25400
     -T14,'P8P2    =',E13.6,T38,'T8T2    =',E13.6,/,                TTY    25500
     -T14,'P80P20  =',E13.6,T38,'T80T20  =',E13.6)                  TTY    25600
C                                                                   TTY    25700
315   FORMAT('0',T14,'SUBSONIC DIFFUSER DATA:')                     TTY    25800
316   FORMAT('0',T14,'RSD     =',E13.6,/,                           TTY    25900
     -T14,'GM      =',E13.6,T38,'A8A7    =',E13.6,/,                TTY    26000
     -T14,'M7      =',E13.6,T38,'M8      =',E13.6,/,                TTY    26100
     -T14,'P8P7    =',E13.6,T38,'T8T7    =',E13.6,/,                TTY    26200
     -T14,'P80P70  =',E13.6,T38,'T80T70  =',E13.6)                  TTY    26300
      END                                                           TTY    26400
```

7.4.2 CLGDOP Sample Case No. 1

```
CLGDOP SAMPLE INPUT DATA: CASE NO.1

INPUT DATA FOR LASER CAVITY ANALYSIS BY NAMELIST.
CURRENT VALUES ARE:

$CAV
 GS=1.56200, M1=5.00000, A2A1=2.55724, C01=1.00000,
 C02=0.00000, NPTS=21, $
 $CAV M1=2.23, A2A1=1.0, C01=0.0, NPTS=5$

INPUT THE VARIABLE TO BE MINIMIZED FROM THE FOLLOWING LIST:

"P60P1" DIMENSIONLESS PRIMARY STAGNATION PRESSURE
"WPWS"  PRIMARY-TO-SECONDARY MASS FLOW RATIO

P60P1

INPUT SYSTEM CONSTRAINTS BY NAMELIST.
CURRENT VALUES ARE:

$CONST2
 P8P1=57.1634, WPWS=1.00000, $
 $CONST2 P8P1=20.7141, WPWS=6.0$

INPUT THE EJECTOR MODEL FROM THE FOLLOWING LIST:

"CAE" CONSTANT-AREA EJECTOR
"SSE" SUPERSONIC-SUPERSONIC EJECTOR

SSE

INPUT DATA FOR EJECTOR ANALYSIS BY NAMELIST.
CURRENT VALUES ARE:

$EJECT2
 GP=1.34000, MWPMWS=1.68375, T60T20=0.761376, A8A7=2.00000, $
 $EJECT2 MWPMWS=1.47815, T60T20=0.807313$
```

7.4.2 CGLDOP Sample Case No. 1 (Cont.)

```
CLGDOP SAMPLE OUTPUT DATA: CASE NO.1


                              SEARCH DATA:

  NTYPE        MS1            WPNS           DMS1        FAIL

    1     0.100000E+01   0.595735E+01   0.100000E+00   NO
    2     0.900000E+00   0.577684E+01   0.100000E+00   NO
    2     0.800000E+00   0.577978E+01   0.100000E+00   NO
    3     0.900000E+00   0.577684E+01   0.100000E+00   NO



         HIGH ENERGY CHEMICAL LASER SYSTEM SIMULATION
                  ONE-DIMENSIONAL ANALYSIS

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                        1 JANUARY 76

              MECHANICAL ENGINEERING DEPARTMENT
         UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
                   URBANA, ILLINOIS 61801

                 CAE SOLUTION FOR MINIMUM WPNS

         SYSTEM DATA:

POINT 1  LASER CAVITY ENTRANCE CONDITIONS

         M1     = 0.500000E+01   GS     = 0.156200E+01
         P1P10  = 0.306353E-02   T1T10  = 0.124611E+00

POINT 2  LASER CAVITY EXIT AND NORMAL SHOCK DIFFUSER
         ENTRANCE CONDITIONS

         GS     = 0.156200E+01
         M2     = 0.218000E+01   A2A1   = 0.255724E+01
         P2P1   = 0.203682E+01   T2T1   = 0.515579E+01
         P20P10 = 0.658641E-01   T20T10 = 0.150000E+01
```

7.4.2 CGLDOP Sample Case No. 1 (Cont.)

```
POINT 3  NORMAL SHOCK DIFFUSER EXIT AND SUBSONIC
         DIFFUSER ENTRANCE CONDITIONS

         GS     = 0.156200E+01
         M3     = 0.571828E+00   A3A1   = 0.255724E+01
         P3P1   = 0.851724E+01   T3T1   = 0.110277E+02
         P30P10 = 0.332875E-01   T30T10 = 0.150000E+01

POINT 4  SUBSONIC DIFFUSER EXIT AND SUDDEN ENLARGEMENT
         ENTRANCE CONDITIONS

         GS     = 0.156200E+01
         M4     = 0.242941E+00   A4A1   = 0.511448E+01
         P4P1   = 0.102350E+02   T4T1   = 0.119445E+02
         P40P10 = 0.327969E-01   T40T10 = 0.150000E+01

POINT 5  CONSTANT-AREA EJECTOR SECONDARY NOZZLE EXIT
         CONDITIONS

         GS     = 0.156200E+01
         M5     = 0.900000E+00   A5A1   = 0.287105E+01
         P5P1   = 0.605933E+01   T5T1   = 0.980845E+01
         P50P10 = 0.327969E-01   T50T10 = 0.150000E+01

POINT 6  CONSTANT-AREA EJECTOR PRIMARY NOZZLE EXIT
         CONDITIONS

         GP     = 0.134000E+01   MWPMWS = 0.166375E+01
         WPWS   = 0.577684E+01
         M6     = 0.495558E+01   A6A1   = 0.106546E+01
         P60P1  = 0.354470E+04   T60T1  = 0.916769E+01
         P60P10 = 0.120751E+02   T60T10 = 0.114206E+01

POINT 7  CONSTANT-AREA EJECTOR EXIT AND SUBSONIC
         DIFFUSER ENTRANCE CONDITIONS

         GM     = 0.137328E+01   MWMMWS = 0.152944E+01
         WMWS   = 0.677684E+01
         M7     = 0.435520E+00   A7A1   = 0.393733E+01
         P7P1   = 0.520506E+02   T7T1   = 0.932738E+01
         P70P10 = 0.181087E+00   T70T10 = 0.120309E+01

POINT 8  SUBSONIC DIFFUSER EXIT CONDITIONS

         GM     = 0.137328E+01   MWMMWS = 0.152944E+01
         WMWS   = 0.677684E+01
         M8     = 0.199607E+00   A8A1   = 0.787466E+01
         P8P1   = 0.571155E+02   T8T1   = 0.958629E+01
         P80P10 = 0.179667E+00   T80T10 = 0.120309E+01
```

7.4.2 CGLDOP Sample Case No. 1 (Cont.)

```
LASER CAVITY DATA:

NPTS   =             21
CO1    = 0.100000E+01   CO2    = 0.000000E+00
GS     = 0.156200E+01   A2A1   = 0.255724E+01
M1     = 0.500000E+01   M2     = 0.218000E+01
P2P1   = 0.203682E+01   T2T1   = 0.515579E+01
P20P10 = 0.658641E-01   T20T10 = 0.150000E+01

NORMAL SHOCK DIFFUSER DATA:

GS     = 0.156200E+01   RNSD   = 0.750000E+00
M2     = 0.218000E+01   M3     = 0.571828E+00
P3P2   = 0.418164E+01   T3T2   = 0.213889E+01
P30P20 = 0.505397E+00   T30T20 = 0.100000E+01

SUBSONIC DIFFUSER DATA:

RSD    = 0.985261E+00
GS     = 0.156200E+01   A4A3   = 0.200000E+01
M3     = 0.571828E+00   M4     = 0.242941E+00
P4P3   = 0.120172E+01   T4T3   = 0.107407E+01
P40P30 = 0.985261E+00   T40T30 = 0.100000E+01

CONSTANT-AREA EJECTOR DATA:

GS     = 0.156200E+01   GP     = 0.134000E+01
GM     = 0.137328E+01   MWPMWS = 0.168375E+01
A7A6   = 0.369544E+01   WPWS   = 0.577684E+01
M6     = 0.495558E+01   M7     = 0.435520E+00
P60P50 = 0.368178E+03   T60T50 = 0.761376E+00
P7P50  = 0.485814E+01   T7T50  = 0.774638E+00
P70P50 = 0.552147E+01   T70T50 = 0.802061E+00

NORMAL SHOCK DIFFUSER - SUBSONIC DIFFUSER -
CONSTANT-AREA EJECTOR DATA:

GS     = 0.156200E+01   GP     = 0.134000E+01
GM     = 0.137328E+01   MWPMWS = 0.168375E+01
A7A2   = 0.153968E+01   A7A6   = 0.369544E+01
WPWS   = 0.577684E+01   M2     = 0.218000E+01
M6     = 0.495558E+01   M7     = 0.435520E+00
P60P2  = 0.193669E+04
P60P20 = 0.183333E+03   T60T20 = 0.761376E+00
P7P2   = 0.255548E+02   T7T2   = 0.180911E+01
P70P20 = 0.274940E+01   T70T20 = 0.802061E+00
```

7.4.2 CGLDOP Sample Case No. 1 (Cont.)

```
NORMAL SHOCK DIFFUSER - SUBSONIC DIFFUSER -
CONSTANT-AREA EJECTOR - SUBSONIC DIFFUSER
DATA:

GS     = 0.156200E+01   GP     = 0.134000E+01
GM     = 0.137328E+01   MWPMWS = 0.168375E+01
A7A2   = 0.153968E+01   A7A6   = 0.369544E+01
A8A7   = 0.200000E+01   WPWS   = 0.577684E+01
M2     = 0.218000E+01   M6     = 0.495558E+01
M7     = 0.435520E+00   M8     = 0.199607E+00
P60P2  = 0.193669E+04
P60P20 = 0.183333E+03   T60T20 = 0.761376E+00
P8P2   = 0.280415E+02   T8T2   = 0.185932E+01
P80P20 = 0.272784E+01   T80T20 = 0.802061E+00

SUBSONIC DIFFUSER DATA:

PSD    = 0.992159E+00
GM     = 0.137328E+01   A8A7   = 0.200000E+01
M7     = 0.435520E+00   M8     = 0.199607E+00
P8P7   = 0.109731E+01   T8T7   = 0.102776E+01
P80P70 = 0.992159E+00   T80T70 = 0.100000E+01


TO RESTART PROGRAM ENTER "YES"
TO STOP PROGRAM ENTER "NO"
YES
```

7.4.3 CLGDOP Sample Case No. 2

```
CLGDOP SAMPLE OUTPUT DATA: CASE NO.2


          HIGH ENERGY CHEMICAL LASER SYSTEM SIMULATION
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              MECHANICAL ENGINEERING DEPARTMENT
           UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
                    URBANA, ILLINOIS 61801

               SSE SOLUTION FOR MINIMUM P60P1

          SYSTEM DATA:

POINT 1   LASER CAVITY ENTRANCE CONDITIONS

          M1     = 0.223000E+01   GS     = 0.156200E+01
          P1P10  = 0.880182E-01   T1T10  = 0.417121E+00

POINT 2   LASER CAVITY EXIT AND SUPERSONIC-SUPERSONIC
          EJECTOR ENTRANCE CONDITIONS

          GS     = 0.156200E+01
          M2     = 0.223000E+01   A2A1   = 0.100000E+01
          P2P1   = 0.100000E+01   T2T1   = 0.100000E+01
          P20P10 = 0.100000E+01   T20T10 = 0.100000E+01

POINT 6   SUPERSONIC-SUPERSONIC EJECTOR PRIMARY NOZZLE
          EXIT CONDITIONS

          GP     = 0.134000E+01   MWPMWS = 0.147815E+01
          WPWS   = 0.599726E+01
          M6     = 0.312691E+01   A6A1   = 0.124839E+01
          P60P1  = 0.123006E+03   T60T1  = 0.193544E+01
          P60P10 = 0.108268E+02   T60T10 = 0.807313E+00

POINT 7   SUPERSONIC-SUPERSONIC EJECTOR EXIT AND
          SUBSONIC DIFFUSER ENTRANCE CONDITIONS

          GM     = 0.136881E+01   MWMMWS = 0.138360E+01
          WMWS   = 0.699726E+01
          M7     = 0.470762E+00   A7A1   = 0.224839E+01
          P7P1   = 0.185762E+02   T7T1   = 0.192517E+01
          P70P10 = 0.189710E+01   T70T10 = 0.835845E+00
```

7.4.3 CLGDOP Sample Case No. 2 (Cont.)

```
CLGDOP SAMPLE INPUT DATA: CASE NO.2

INPUT DATA FOR LASER CAVITY ANALYSIS BY NAMELIST.
CURRENT VALUES ARE:

$CAV
 GS=1.40000, M1=2.00000, A2A1=1.00000, CQ1=0.00000,
 CQ2=0.00000, NPTS=21, $
 $CAV GS=1.562, M1=5.0, A2A1=2.55724, CQ1=1.0$

INPUT THE VARIABLE TO BE MINIMIZED FROM THE FOLLOWING LIST:

 P60P1" DIMENSIONLESS PRIMARY STAGNATION PRESSURE
"WPWS"  PRIMARY-TO-SECONDARY MASS FLOW RATIO

WPWS

INPUT SYSTEM CONSTRAINTS BY NAMELIST.
CURRENT VALUES ARE:

$CONST1
 P8P1=76.0000, P60P1=2500.00, $
 $CONST1 P8P1=57.1634, P60P1=3945.83$

INPUT THE EJECTOR MODEL FROM THE FOLLOWING LIST:

'CAE" CONSTANT-AREA EJECTOR
'SSE" SUPERSONIC-SUPERSONIC EJECTOR

CAE

INPUT DATA FOR SUPERSONIC-SUBSONIC DIFFUSER SECTION BY
NAMELIST.  CURRENT VALUES ARE:

$DIFUSR
 PNSD=1.00000, A4A3=1.00000, $
 $DIFUSR PNSD=0.75, A4A3=2.0$

INPUT DATA FOR EJECTOR ANALYSIS BY NAMELIST.
CURRENT VALUES ARE:

$EJECT1
 GP=1.40000, MWPMWS=1.00000, T60T50=1.00000, A8A7=1.00000, $
 $EJECT1 GP=1.34, MWPMWS=1.68375, T60T50=0.761376, A8A7=2.0$
```

7.4.3 CLGDOP Sample Case No. 2 (Cont.)

```
POINT 8  SUBSONIC DIFFUSER EXIT CONDITIONS

         GM     = 0.136881E+01   MWMMWS = 0.138360E+01
         WMWS   = 0.699726E+01
         M8     = 0.212559E+00   A8A1   = 0.449679E+01
         P8P1   = 0.207098E+02   T8T1   = 0.198729E+01
         P80P10 = 0.187984E+01   T80T10 = 0.835845E+00

         LASER CAVITY DATA:

         NPTS   =              5
         CO1    = 0.000000E+00   CO2    = 0.000000E+00
         GS     = 0.156200E+01   A2A1   = 0.100000E+01
         M1     = 0.223000E+01   M2     = 0.223000E+01
         P2P1   = 0.100000E+01   T2T1   = 0.100000E+01
         P20P10 = 0.100000E+01   T20T10 = 0.100000E+01

         SUPERSONIC-SUPERSONIC EJECTOR DATA:

         GS     = 0.156200E+01   GP     = 0.134000E+01
         GM     = 0.136881E+01   MWPMWS = 0.147815E+01
         A7A2   = 0.224839E+01   A7A6   = 0.180103E+01
         WPWS   = 0.599726E+01   M2     = 0.223000E+01
         M6     = 0.312691E+01   M7     = 0.470762E+00
         P60P2  = 0.123006E+03
         P60P20 = 0.108268E+02   T60T20 = 0.807313E+00
         P7P2   = 0.185762E+02   T7T2   = 0.192517E+01
         P70P20 = 0.189710E+01   T70T20 = 0.835845E+00

         SUPERSONIC-SUPERSONIC EJECTOR - SUBSONIC
         DIFFUSER DATA:

         GS     = 0.156200E+01   GP     = 0.134000E+01
         GM     = 0.136881E+01   MWPMWS = 0.147815E+01
         A7A2   = 0.224839E+01   A7A6   = 0.180103E+01
         A8A7   = 0.200000E+01   WPWS   = 0.599726E+01
         M2     = 0.223000E+01   M6     = 0.312691E+01
         M7     = 0.470762E+00   M8     = 0.212559E+00
         P60P2  = 0.123006E+03
         P60P20 = 0.108268E+02   T60T20 = 0.807313E+00
         P8P2   = 0.207098E+02   T8T2   = 0.198729E+01
         P80P20 = 0.187984E+01   T80T20 = 0.835845E+00

         SUBSONIC DIFFUSER DATA:

         PSD    = 0.990902E+00
         GM     = 0.136881E+01   A8A7   = 0.200000E+01
         M7     = 0.470762E+00   M8     = 0.212559E+00
         P8P7   = 0.111485E+01   T8T7   = 0.103227E+01
         P80P70 = 0.990902E+00   T80T70 = 0.100000E+01

TO RESTART PROGRAM ENTER "YES"
TO STOP PROGRAM ENTER "NO"
NO
```

7.5 CHEMICAL LASER GAS DYNAMICS SYSTEM PROGRAM

7.5.1 Computer Program (CLGDSP)

```
C     ******************************************************************
C     *                                                                *
C     *    CHEMICAL LASER GAS DYNAMICS SYSTEM PROGRAM (CLGDSP)         *
C     *                                                                *
C     *                 WRITTEN BY: A.L. ADDY                          *
C     *                             C.D. MIKKELSEN                     *
C     *                             M.R. SANDBERG                      *
C     *                                                                *
C     *                      1 JANUARY 76                              *
C     *                                                                *
C     *              MECHANICAL ENGINEERING DEPARTMENT                 *
C     *         UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN             *
C     *                  URBANA, ILLINOIS 61801                        *
C     *                                                                *
C     *  CLGDSP IS A PROGRAM FOR SIMULATING THE GAS DYNAMICS           *
C     *  OF HIGH-ENERGY CHEMICAL LASER SYSTEMS BY ONE-                 *
C     *  DIMENSIONAL ANALYSIS. CLGDSP IS A FORTRAN IV PROGRAM          *
C     *  WRITTEN FOR DEC SYSTEM-10 (F40).                              *
C     *                                                                *
C     ******************************************************************
C
C     ******************************************************************
C     *                                                                *
C     *                     NOTATION SCHEME                            *
C     *                                                                *
C     *  VARIABLES ARE DEFINED AS FOLLOWS:                             *
C     *                                                                *
C     *  A : AREA                                                      *
C     *  G : (GAMMA) SPECIFIC HEAT RATIO                               *
C     *  M : MACH NUMBER                                               *
C     *  MW: MOLECULAR WEIGHT                                          *
C     *  P : PRESSURE                                                  *
C     *  T : TEMPERATURE                                               *
C     *  W : MASS FLOW RATE                                            *
C     *                                                                *
C     *  REPEATED LETTERS INDICATE RATIOS.                             *
C     *  EXAMPLE: A2A1=A2/A1                                           *
C     *                                                                *
C     *  VARIABLES ARE DESIGNATED AS TO LOCATION BY THE                *
C     *  FOLLOWING:                                                    *
C     *                                                                *
C     *  POINT 1: LASER CAVITY ENTRANCE                                *
C     *  POINT 2: LASER CAVITY EXIT                                    *
C     *  POINT 3: NORMAL SHOCK DIFFUSER EXIT                           *
C     *  POINT 4: SUBSONIC DIFFUSER EXIT                               *
C     *  POINT 5: EJECTOR SECONDARY NOZZLE EXIT                        *
C     *  POINT 6: EJECTOR PRIMARY NOZZLE EXIT                          *
C     *  POINT 7: EJECTOR MIXING TUBE EXIT                             *
C     *  POINT 8: SUBSONIC DIFFUSER EXIT                               *
C     *  EXAMPLE: P8P2= SUBSONIC DIFFUSER EXIT-TO-LASER CAVITY         *
```

7.5.1 CLGDSP (Cont.)

```
C     *             EXIT STATIC PRESSURE RATIO                            *
C     *                                                                   *
C     *   S: INDICATES SECONDARY OR DRIVEN STREAM PROPERTIES              *
C     *   P: INDICATES PRIMARY OR DRIVING STREAM PROPERTIES               *
C     *   M: INDICATES MIXED STREAM PROPERTIES                            *
C     *   EXAMPLE: GM= MIXED STREAM SPECIFIC HEAT RATIO                   *
C     *                                                                   *
C     *   O: INDICATES STAGNATION CONDITIONS                              *
C     *   EXAMPLE: T20T10= LASER CAVITY EXIT-TO-ENTRANCE                  *
C     *            STAGNATION TEMPERATURE RATIO                           *
C     *                                                                   *
C     *   VARIABLES NOT FOLLOWING THIS SCHEME ARE DEFINED                 *
C     *   AS REQUIRED.                                                    *
C     *                                                                   *
C     *********************************************************************
C
C
      IMPLICIT REAL*4 (M)
      REAL*4 NO
C
      COMMON/TTY1/A2A1,A3A1,A4A1,A4A3,A5A1,A5A6,A6A1,A7A1,A7A2,
     -A7A6,A8A1,A8A7
      COMMON/TTY2/COEFF,CQ1,CQ2,EJECT,GM,GP,GS
      COMMON/TTY3/M1,M2,M3,M4,M5,M6,M7,M8,MWMMWS,MWPMWS,NPTS
      COMMON/TTY4/P1P10,P2P1,P20P10,P3P1,P30P10,P3P2,P30P20,
     -P4P1,P40P10,P4P3,P40P30,P5P1,P50P10,P60P1,P60P10,P60P2,
     -P60P20,P60P50,P7P1,P70P10,P7P2,P70P20,P7P50,P70P50,XP8P1,
     -P80P10,P8P2,P80P20,P8P7,P80P70
      COMMON/TTY5/RCPE,RNSD,RSD34,RSD78
      COMMON/TTY6/T1T10,T2T1,T20T10,T3T1,T30T10,T3T2,T30T20,
     -T4T1,T40T10,T4T3,T40T30,T5T1,T50T10,T60T1,T60T10,T60T20,
     -T60T50,T7T1,T70T10,T7T2,T70T20,T7T50,T70T50,T8T1,
     -T80T10,T8T2,T80T20,T8T7,T80T70
      COMMON/TTY7/WMWS,WPWS
C
      DATA CPE/'CPE'/,CAE/'CAE'/,SSE/'SSE'/,WPWSC/'WPWS'/,
     -M6C/'M6'/,A7A6C/'A7A6'/,YES/'YES'/,NO/'NO'/
C
      DATA GS,M1,A2A1,CQ1,CQ2,NPTS,P8P1/1.400,2.0,1.0,2*0.0,21,
     -10.0/
      DATA RNSD,A4A3/2*1.0/
      DATA GP,MWPMWS,T60T50,T60T20,M6,A7A6,WPWS,RCPE,A8A7/
     -1.400,3*1.0,1.01,10.0,3*1.0/
C
      NAMELIST/CAV/GS,M1,A2A1,CQ1,CQ2,NPTS,P8P1
      NAMELIST/DIFUSR/RNSD,A4A3
      NAMELIST/EJECT1/GP,MWPMWS,T60T50,M6,A7A6,WPWS,RCPE,A8A7
      NAMELIST/EJECT2/GP,MWPMWS,T60T50,M6,A7A6,WPWS,A8A7
      NAMELIST/EJECT3/GP,MWPMWS,T60T20,M6,A7A6,A8A7
C
```

```
      TOTM(GX,MX)=1.0+((GX-1.0)/2.0)*MX*MX
      POPM(GX,MX)=(1.0+((GX-1.0)/2.0)*MX*MX)**(GX/(GX-1.0))
      WM(GX,MX)=MX*SQRT(GX*(1.0+((GX-1.0)/2.0)*MX*MX))
C
C
C     ************************************************************
C     *                                                          *
C     *           SECTION I: LASER CAVITY ANALYSIS               *
C     *                                                          *
C     *    VARIABLES USED IN THIS SECTION AND THEIR DEFAULT      *
C     *    VALUES ARE:                                           *
C     *                                                          *
C     *    1. GS(1.400)  : RATIO OF SPECIFIC HEATS               *
C     *    2. M1(2.0)    : CAVITY ENTRANCE MACH NUMBER           *
C     *    3. A2A1(1.0)  : CAVITY EXIT-TO-ENTRANCE AREA RATIO    *
C     *    4. CQ1(0.0)   : HEAT ADDITION COEFFICIENT             *
C     *    5. CQ2(0.0)   : HEAT ADDITION COEFFICIENT             *
C     *    6. NPTS(21)   : CAVITY INTEGRATION INCREMENTS         *
C     *    7. P8P1(10.0) : SUBSONIC DIFFUSER EXIT-TO-CAVITY      *
C     *                    ENTRANCE STATIC PRESSURE RATIO        *
C     *                                                          *
C     *    NOTES:                                                *
C     *    1. VALUES OF ALL INPUT VARIABLES MUST BE DEFINED      *
C     *       EITHER BY INPUT OR DEFAULT.                        *
C     *    2. ALL VARIABLE INPUT IS BY NAMELIST.                 *
C     *    3. THE MAXIMUM NUMBER OF INTEGRATION STEPS IS 25.     *
C     *                                                          *
C     ************************************************************
C
C
100   WRITE(5,200)
      WRITE(5,CAV)
      READ(5,CAV)
      X1=0.0
      X2=1.0
      A1=1.0
      A2=A2A1
      FAIL=NO
C
C
C     ************************************************************
C     *                                                          *
C     *             CALCULATIONS FOR LASER CAVITY                *
C     *                                                          *
C     ************************************************************
C
C
      CALL CAVITY(GS,M1,X1,X2,A1,A2,CQ1,CQ2,NPTS,M2,T2T1,T20T10,
     -P2P1,P20P10,FAIL)
      T1T10=1.0/TOTM(GS,M1)
```

```
      P1P10=1.0/POPM(GS,M1)
      T20T2=TOTM(GS,M2)
      P20P2=POPM(GS,M2)
      IF(FAIL.EQ.YES) GO TO 113
C
C
C     ***********************************************************
C     *                                                         *
C     *              SECTION II: EJECTOR ANALYSIS               *
C     *                                                         *
C     *    THE PROGRAMMER MAY CHOOSE ONE OF THREE EJECTOR       *
C     *    CONFIGURATIONS TO REPRESSURIZE THE CAVITY FLOW.      *
C     *    THESE CONFIGURATIONS ARE:                            *
C     *                                                         *
C     *    1. CPE: CONSTANT-PRESSURE EJECTOR                    *
C     *    2. CAE: CONSTANT-AREA EJECTOR                        *
C     *    3. SSE: SUPERSONIC-SUPERSONIC EJECTOR                *
C     *                                                         *
C     *    AFTER THE CHOICE OF EJECTOR SYSTEM HAS BEEN MADE.    *
C     *    THE PROGRAMMER MUST CHOOSE AN ITERATION VARIABLE.    *
C     *                                                         *
C     *    FOR CPE AND CAE, THE PROGRAMMER MUST CHOOSE AN       *
C     *    ITERATION VARIABLE FROM THE FOLLOWING LIST:          *
C     *                                                         *
C     *    1. M6  : PRIMARY NOZZLE EXIT MACH NUMBER             *
C     *    2. A7A6: MIXING TUBE EXIT-TO-PRIMARY NOZZLE EXIT     *
C     *             AREA RATIO                                  *
C     *    3. WPWS: PRIMARY-TO-SECONDARY MASS FLOW RATIO        *
C     *                                                         *
C     *    FOR SSE, THE PROGRAMMER MUST CHOOSE AN ITERATION     *
C     *    VARIABLE FROM THE FOLLOWING LIST:                    *
C     *                                                         *
C     *    1. M6  : PRIMARY NOZZLE EXIT MACH NUMBER             *
C     *    2. A7A6: MIXING TUBE EXIT-TO-PRIMARY NOZZLE EXIT     *
C     *             AREA RATIO                                  *
C     *                                                         *
C     ***********************************************************
C
C
      WRITE(5,201)
      READ(5,202)EJECT
      WRITE(5,203)
      IF(EJECT.NE.SSE) WRITE(5,204)
      READ(5,205)COEFF
C
C
C     ***********************************************************
C     *                                                         *
C     *     VARIABLES USED IN THIS SECTION AND THEIR DEFAULT    *
C     *     VALUES ARE:                                         *
```

```
C      *                                                             *
C      *  1. RNSD(1.0)   : NORMAL SHOCK DIFFUSED COEFFICIENT          *
C      *  2. A4A3(1.0)   : SUBSONIC DIFFUSER EXIT-TO-ENTRANCE         *
C      *                   AREA RATIO                                 *
C      *  3. GP(1.400)   : RATIO OF SPECIFIC HEATS                    *
C      *  4. MWPMWS(1.0): PRIMARY-TO-SECONDARY MOLECULAR              *
C      *                   WEIGHT RATIO                               *
C      *  5. T60T50(1.0): PRIMARY-TO-SECONDARY STAGNATION             *
C      *                   TEMPERATURE RATIO (FOR CPE AND CAE)        *
C      *  5. T60T20(1.0): PRIMARY-TO-SECONDARY STAGNATION             *
C      *                   TEMPERATURE RATIO (FOR SSE)                *
C      *  6. M6(1.01)    : PRIMARY NOZZLE EXIT MACH NUMBER            *
C      *  7. A7A6(10.0)  : MIXING TUBE EXIT-TO-PRIMARY NOZZLE         *
C      *                   EXIT AREA RATIO                            *
C      *  8. WPWS(1.0)   : PRIMARY-TO-SECONDARY MASS FLOW RATIO       *
C      *  9. RCPE(1.0)   : NORMAL SHOCK COEFFICIENT FOR               *
C      *                   CONSTANT-PRESSURE EJECTOR                  *
C      * 10. A8A7(1.0)   : SUBSONIC DIFFUSER EXIT-TO-ENTRANCE         *
C      *                   AREA RATIO                                 *
C      *                                                             *
C      *     ALL VARIABLE INPUT IS BY NAMELIST.                      *
C      *                                                             *
C      ***************************************************************
C
C
      IF(EJECT.EQ.SSE) GO TO 102
      WRITE(5,206)
      WRITE(5,DIFUSR)
      READ(5,DIFUSR)
      WRITE(5,207)
      IF(EJECT.NE.CPE) GO TO 101
      WRITE(5,EJECT1)
      READ(5,EJECT1)
      GO TO 103
101   WRITE(5,EJECT2)
      READ(5,EJECT2)
      GO TO 103
102   WRITE(5,207)
      WRITE(5,EJECT3)
      READ(5,EJECT3)
103   MWSMWP=1.0/MWPMWS
      T50T60=1.0/T60T50
      T20T60=1.0/T60T20
      WSWP=1.0/WPWS
      NIT=1
      NTYPE=1
C
C
C      ***************************************************************
C      *                                                             *
```

7.5.1 CLGDSP (Cont.)

```
C     *            CACULATIONS FOR NORMAL SHOCK DIFFUSER              *  CLGDSP 25100
C     *                                                               *  CLGDSP 25200
C     *****************************************************************  CLGDSP 25300
C                                                                        CLGDSP 25400
C                                                                        CLGDSP 25500
      IF(EJECT.EQ.SSE) GO TO 104                                         CLGDSP 25600
      CALL NSDS(GS,M2,RNSD,M3,P3P2,P30P20,T3T2,T30T20)                   CLGDSP 25700
      P3P1=P3P2*P2P1                                                     CLGDSP 25800
      T3T1=T3T2*T2T1                                                     CLGDSP 25900
      P30P10=P30P20*P20P10                                               CLGDSP 26000
      T30T10=T30T20*T20T10                                               CLGDSP 26100
      A3A1=A2A1                                                          CLGDSP 26200
C                                                                        CLGDSP 26300
C                                                                        CLGDSP 26400
C     *****************************************************************  CLGDSP 26500
C     *                                                               *  CLGDSP 26600
C     *            CALCULATICNS FOR SUBSONIC DIFFUSER                 *  CLGDSP 26700
C     *                                                               *  CLGDSP 26800
C     *****************************************************************  CLGDSP 26900
C                                                                        CLGDSP 27000
C                                                                        CLGDSP 27100
      CALL SDS(GS,M3,A4A3,M4,P4P3,P40P30,T4T3,T40T30,RSD34,FAIL)         CLGDSP 27200
      IF(FAIL.EC.YES) GC TO 114                                          CLGDSP 27300
      P4P1=P4P3*P3P1                                                     CLGDSP 27400
      T4T1=T4T3*T3T1                                                     CLGDSP 27500
      P40P10=P40P30*P30P10                                               CLGDSP 27600
      T40T10=T40T30*T30T10                                               CLGDSP 27700
      A4A1=A4A3*A3A1                                                     CLGDSP 27800
C                                                                        CLGDSP 27900
C                                                                        CLGDSP 28000
C     *****************************************************************  CLGDSP 28100
C     *                                                               *  CLGDSP 28200
C     *            CALCULATICNS FOR SUDCEN ENLARGEMENT                *  CLGDSP 28300
C     *                                                               *  CLGDSP 28400
C     *****************************************************************  CLGDSP 28500
C                                                                        CLGDSP 28600
C                                                                        CLGDSP 28700
      P50P40=1.0                                                         CLGDSP 28800
      T50T40=1.C                                                         CLGDSP 28900
      P50P20=P50P40*P40P30*P30P20                                        CLGDSP 29000
      T50T20=T50T40*T40T30*T30T20                                        CLGDSP 29100
      P50P10=P50P20*P20P10                                               CLGDSP 29200
      T50T10=T50T20*T20T1C                                               CLGDSP 29300
C                                                                        CLGDSP 29400
C                                                                        CLGDSP 29500
C     *****************************************************************  CLGDSP 29600
C     *                                                               *  CLGDSP 29700
C     *         CALCULATIONS FOR CONSTANT-PRESSURE EJECTOR            *  CLGDSP 29800
C     *                                                               *  CLGDSP 29900
C     *****************************************************************  CLGDSP 30000
```

7.5.1 CLGDSP (Cont.)

```
C
C
104   DO 108 KOUNT=1,100
      IF(EJECT.NE.CPE) GO TO 105
      CALL CPES(GS,GP,MWSMWP,T50T60,WSWP,M6,A7A6,RCPE,M5,A5A6,
     -GM,MWMMWP,T70T60,M7,P60P50,P7P50,FAIL)
      IF(FAIL.EG.YES) GO TO 115
      P7P1=P7P5C*P50P20*P20P2*P2P1
      GO TO 107
C
C
C     ***********************************************************
C     *                                                         *
C     *          CALCULATIONS FOR CONSTANT-AREA EJECTOR         *
C     *                                                         *
C     ***********************************************************
C
C
105   IF(EJECT.NE.CAE) GO TO 106
      A6A7=1.0/A7A6
      CALL CAES(GS,GP,MWSMWP,T50T60,WSWP,M6,A6A7,M5,GM,MWMMWP,
     -T70T60,M7,P60P50,P7P50,FAIL)
      IF(FAIL.EG.YES) GO TO 116
      P7P1=P7P5C*P5CP20*P20P2*P2P1
      GO TO 107
C
C
C     ***********************************************************
C     *                                                         *
C     *      CALCULATIONS FOR SUPERSONIC-SUPERSONIC EJECTOR     *
C     *                                                         *
C     ***********************************************************
C
C
106   A2A6=A7A6-1.0
      CALL SSES(GS,GP,MWSMWP,T20T60,M2,M6,A2A6,WSWP,GM,MWMMWP,
     -T70T60,M7,P60P2,P7P2,FAIL)
      IF(FAIL.EG.YES) GO TO 117
      P7P1=P7P2*P2P1
C
C
C     ***********************************************************
C     *                                                         *
C     *            CALCULATIONS FOR SUBSONIC DIFFUSER           *
C     *                                                         *
C     ***********************************************************
C
C
107   CALL SDS(GM,M7,A8A7,M8,P8P7,P80P70,T8T7,T80T70,RSD78,FAIL)
      IF(FAIL.EQ.YES) GO TO 118
```

```
      XP8P1=P8P7*P7P1
C
C
C     ****************************************************************
C     *                                                              *
C     *                     ITERATICN SCHEME                         *
C     *                                                              *
C     ****************************************************************
C
C
      IF(COEFF.EQ.M6C) CALL ITER(M6,0.5,1.0E-06,1.0,XP8P1,P8P1,
     -1.0E-01,NIT,NTYPE,XNEG,YNEG,XPOS,YPOS,NSIGN1,NSIGN2)
      IF(COEFF.EQ.A7A6C) CALL ITER(A7A6,0.5,1.0E-06,-1.0,XP8P1,
     -P8P1,1.0E-01,NIT,NTYPE,XNEG,YNEG,XPOS,YPOS,NSIGN1,NSIGN2)
      IF(COEFF.EQ.WPWSC) CALL ITER(WSWP,0.1,1.0E-06,-1.0,XP8P1,
     -P8P1,1.0E-01,NIT,NTYPE,XNEG,YNEG,XPOS,YPOS,NSIGN1,NSIGN2)
  108 IF(NTYPE.EQ.3) GO TO 109
      IF(COEFF.EQ.M6C) GO TO 119
      IF(CCEFF.EQ.A7A6C) GO TO 120
      IF(COEFF.EQ.WPWSC) GO TO 121
  109 MWMMWS=MWMMWP*MWPMWS
      WPWS=1.0/WSWP
      WMWS=1.0+WPWS
C
C
C     ****************************************************************
C     *                                                              *
C     *               FINAL CALCULATIONS FOR CPE/CAE                 *
C     *                                                              *
C     ****************************************************************
C
C
      IF(EJECT.EQ.SSE) GO TO 110
      P5P1=P50P20*P2CP2*P2P1/POPM(GS,M5)
      T5T1=T50T20*T20T2*T2T1/TOTM(GS,M5)
      A5A1=SQRT(T50T10)*WM(GS,M1)/(P5P1*WM(GS,M5))
      P70P50=POFM(GM,M7)*P7P50
      T70T50=T70T60*T60T50
      T7T50=T70T50/TOTM(GM,M7)
      IF(EJECT.EQ.CAE) A7A6=1.0/A6A7
      GO TC 111
C
C
C     ****************************************************************
C     *                                                              *
C     *                FINAL CALCULATICNS FOR SSE                    *
C     *                                                              *
C     ****************************************************************
C
C
```

7.5.1 CLGDSP (Cont.)

```
110   P60P20=P60P2/P20P2                                              CLGDSP 40100
      P70P20=P0FM(GM,M7)*P7P2/P20P2                                   CLGDSP 40200
      T70T20=T70T60*T60T20                                            CLGDSP 40300
      T7T2=T20T2*T70T20/TOTM(GM,M7)                                   CLGDSP 40400
      A7A2=A7A6/A2A6                                                  CLGDSP 40500
      GO TO 112                                                       CLGDSP 40600
C                                                                     CLGDSP 40700
C                                                                     CLGDSP 40800
C     **********************************************************     CLGDSP 40900
C     *                                                        *     CLGDSP 41000
C     *          FINAL CALCULATIONS FOR NSD-SD-SE-CPE/CAE      *     CLGDSP 41100
C     *                                                        *     CLGDSP 41200
C     **********************************************************     CLGDSP 41300
C                                                                     CLGDSP 41400
C                                                                     CLGDSP 41500
111   P60P2=P60P50*P50P20*P20P2                                       CLGDSP 41600
      P60P20=P60P50*P50P20                                            CLGDSP 41700
      T60T20=T60T50*T50T20                                            CLGDSP 41800
      P7P2=P7P50*P50P20*P20P2                                         CLGDSP 41900
      P70P20=P70P50*P50P20                                            CLGDSP 42000
      T7T2=T7T50*T50T20*T20T2                                         CLGDSP 42100
      T70T20=T70T50*T50T20                                            CLGDSP 42200
      A7A2=WMWS*SQRT(T70T20/MWMMWS)*WM(GS,M2)/(P7P2*WM(GM,M7))        CLGDSP 42300
C                                                                     CLGDSP 42400
C                                                                     CLGDSP 42500
C     **********************************************************     CLGDSP 42600
C     *                                                        *     CLGDSP 42700
C     *        FINAL CALCULATIONS FOR NSD-SD-SE-CPE/CAE-SD     *     CLGDSP 42800
C     *        OR SSE-SD                                       *     CLGDSP 42900
C     *                                                        *     CLGDSP 43000
C     **********************************************************     CLGDSP 43100
C                                                                     CLGDSP 43200
C                                                                     CLGDSP 43300
112   P8P2=P8P7*P7P2                                                  CLGDSP 43400
      P80P20=P80P70*P70P20                                            CLGDSP 43500
      T8T2=T8T7*T7T2                                                  CLGDSP 43600
      T80T20=T80T70*T70T20                                            CLGDSP 43700
C                                                                     CLGDSP 43800
C                                                                     CLGDSP 43900
C     **********************************************************     CLGDSP 44000
C     *                                                        *     CLGDSP 44100
C     *                FINAL SYSTEM CALCULATIONS               *     CLGDSP 44200
C     *                                                        *     CLGDSP 44300
C     **********************************************************     CLGDSP 44400
C                                                                     CLGDSP 44500
C                                                                     CLGDSP 44600
      A7A1=A7A2*A2A1                                                  CLGDSP 44700
      A6A1=A7A1/A7A6                                                  CLGDSP 44800
      A8A1=A8A7*A7A1                                                  CLGDSP 44900
      P60P1=P60P2*P2P1                                                CLGDSP 45000
```

7.5.1 CLGDSP (Cont.)

```
      P60P10=P60P20*P20P10                                          CLGDSP 45100
      T60T1=T60T20*T20T2*T2T1                                       CLGDSP 45200
      T60T10=T60T20*T20T10                                          CLGDSP 45300
      P7P1=P7P2*P2P1                                                CLGDSP 45400
      P70P10=P70P20*P20P10                                          CLGDSP 45500
      T7T1=T7T2*T2T1                                                CLGDSP 45600
      T70T10=T70T20*T20T10                                          CLGDSP 45700
      P80P10=P80P20*P20P10                                          CLGDSP 45800
      T8T1=T8T2*T2T1                                                CLGDSP 45900
      T80T10=T80T20*T20T10                                          CLGDSP 46000
C                                                                   CLGDSP 46100
C                                                                   CLGDSP 46200
C     ************************************************************  CLGDSP 46300
C     *                                                          *  CLGDSP 46400
C     *                     OUTPUT RESULTS                       *  CLGDSP 46500
C     *                                                          *  CLGDSP 46600
C     ************************************************************  CLGDSP 46700
C                                                                   CLGDSP 46800
C                                                                   CLGDSP 46900
      CALL TTY                                                      CLGDSP 47000
      GO TO 122                                                     CLGDSP 47100
C                                                                   CLGDSP 47200
C                                                                   CLGDSP 47300
C     ************************************************************  CLGDSP 47400
C     *                                                          *  CLGDSP 47500
C     *                  FAILURE INDICATORS                      *  CLGDSP 47600
C     *                                                          *  CLGDSP 47700
C     ************************************************************  CLGDSP 47800
C                                                                   CLGDSP 47900
C                                                                   CLGDSP 48000
113   WRITE(5,300)                                                  CLGDSP 48100
      GO TO 122                                                     CLGDSP 48200
114   WRITE(5,301)                                                  CLGDSP 48300
      GO TO 122                                                     CLGDSP 48400
115   WRITE(5,302)                                                  CLGDSP 48500
      GO TO 122                                                     CLGDSP 48600
116   WRITE(5,303)                                                  CLGDSP 48700
      GO TO 122                                                     CLGDSP 48800
117   WRITE(5,304)                                                  CLGDSP 48900
      GO TO 122                                                     CLGDSP 49000
118   WRITE(5,305)                                                  CLGDSP 49100
      GO TO 122                                                     CLGDSP 49200
119   WRITE(5,306)M6,XF8P1,P8P1                                     CLGDSP 49300
      GO TO 122                                                     CLGDSP 49400
120   WRITE(5,307)A7A6,XP8P1,P8P1                                   CLGDSP 49500
      GO TO 122                                                     CLGDSP 49600
121   WRITE(5,308)WSWP,XP8P1,P8P1                                   CLGDSP 49700
122   WRITE(5,208)                                                  CLGDSP 49800
      READ(5,209)RUN                                                CLGDSP 49900
      IF(RUN.EQ.YES) GO TO 100                                      CLGDSP 50000
```

```
C                                                                      CLGDSP 50100
C                                                                      CLGDSP 50200
C     ***************************************************************  CLGDSP 50300
C     *                                                             *  CLGDSP 50400
C     *                    FORMAT STATEMENTS                        *  CLGDSP 50500
C     *                                                             *  CLGDSP 50600
C     ***************************************************************  CLGDSP 50700
C                                                                      CLGDSP 50800
C                                                                      CLGDSP 50900
200   FORMAT('0',T2,'INPUT DATA FOR LASER CAVITY ANALYSIS BY ',        CLGDSP 51000
     -'NAMELIST.',/,T2,'CURRENT VALUES ARE:',/)                        CLGDSP 51100
201   FORMAT('0',T2,'INPUT THE EJECTOR MODEL FROM THE ',               CLGDSP 51200
     -'FOLLOWING LIST:',//,T2,                                         CLGDSP 51300
     -'"CPE" CONSTANT-PRESSURE EJECTOR',/,T2,                          CLGDSP 51400
     -'"CAE" CONSTANT-AREA EJECTOR',/,T2,                              CLGDSP 51500
     -'"SSE" SUPERSONIC-SUPERSONIC EJECTOR',/)                         CLGDSP 51600
202   FORMAT(A3)                                                       CLGDSP 51700
203   FORMAT('0',T2,'INPUT THE ITERATION VARIABLE FROM THE ',          CLGDSP 51800
     -'FOLLOWING LIST:',//,T2,                                         CLGDSP 51900
     -'"M6" PRIMARY NOZZLE EXIT MACH NUMBER',/,T2,                     CLGDSP 52000
     -'"A7A6" MIXING TUBE EXIT-TO-PRIMARY NOZZLE EXIT AREA ',          CLGDSP 52100
     -'RATIO')                                                         CLGDSP 52200
204   FORMAT(' ',T2,'"WPWS" PRIMARY-TO-SECONDARY MASS FLOW ',          CLGDSP 52300
     -'RATIO')                                                         CLGDSP 52400
205   FORMAT(A4)                                                       CLGDSP 52500
206   FORMAT('0',T2,'INPUT DATA FOR SUPERSONIC-SUBSONIC ',             CLGDSP 52600
     -'DIFFUSER SECTION BY NAMELIST.',/,T2,'CURRENT VALUES ARE:',      CLGDSP 52700
     -/)                                                               CLGDSP 52800
207   FORMAT('0',T2,'INPUT DATA FOR EJECTOR ANALYSIS BY ',             CLGDSP 52900
     -'NAMELIST.',/,T2,'CURRENT VALUES ARE:',/)                        CLGDSP 53000
208   FORMAT('1',T2,'TO RESTART PROGRAM ENTER "YES"',/,T2,             CLGDSP 53100
     -'TO STOP PROGRAM ENTER "NO"')                                    CLGDSP 53200
209   FORMAT(A3)                                                       CLGDSP 53300
C                                                                      CLGDSP 53400
300   FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE CAVITY')         CLGDSP 53500
301   FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE SDS',/,          CLGDSP 53600
     -T2,'AT STATION 3 TO 4 IN CHEMICAL LASER SYSTEM')                 CLGDSP 53700
302   FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE CPES')           CLGDSP 53800
303   FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE CAES')           CLGDSP 53900
304   FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE SSES')           CLGDSP 54000
305   FORMAT('0',T2,'PROGRAM TERMINATED IN SUBROUTINE SDS',/,          CLGDSP 54100
     -T2,'AT STATION 7 TO 8 IN CHEMICAL LASER SYSTEM')                 CLGDSP 54200
306   FORMAT('0',T2,'CONVERGENCE FAILURE IN MAIN PROGRAM',/,           CLGDSP 54300
     -T2,'M6 =',E13.6,5X,'XP8P1 =',E13.6,5X,'P8P1 =',E13.6)            CLGDSP 54400
307   FORMAT('0',T2,'CONVERGENCE FAILURE IN MAIN PROGRAM',/,           CLGDSP 54500
     -T2,'A7A6 =',E13.6,5X,'XP8P1 =',E13.6,5X,'P8P1 =',E13.6)          CLGDSP 54600
308   FORMAT('0',T2,'CONVERGENCE FAILURE IN MAIN PROGRAM',/,           CLGDSP 54700
     -T2,'WSWP =',E13.6,5X,'XP8P1 =',E13.6,5X,'P8P1 =',E13.6)          CLGDSP 54800
      END                                                              CLGDSP 54900
```

7.5.1 CLGDSP (Cont.)

```
C       ***********************************************************
C       *                                                         *
C       *              LASER CAVITY SUBROUTINE (CAVITY)           *
C       *                                                         *
C       ***********************************************************
C
C       ***********************************************************
C       *                                                         *
C       *  SUBROUTINE CAVITY IS A SIMPLIFIED FLOW MODEL TO        *
C       *  ASSESS QUALITATIVELY THE EFFECTS OF HEAT RELEASE AND   *
C       *  AREA CHANGE ON THE LASER CAVITY FLOW.  THE FLOW MODEL  *
C       *  IS BASED ON THE ASSUMPTION OF A 1-D FLOW OF AN IDEAL   *
C       *  HOMOGENEOUS GAS THROUGH A CHANNEL WITH A LINEAR        *
C       *  VARIATION IN AREA AND HEAT ADDITION.                   *
C       *                                                         *
C       *  INPUT VARIABLES:                                       *
C       *                                                         *
C       *  G       = SPECIFIC HEAT RATIO                          *
C       *  M1      = ENTRANCE MACH NUMBER                         *
C       *  X1      = ENTRANCE COORDINATE                          *
C       *  X2      = EXIT COORDINATE                              *
C       *  A1      = ENTRANCE AREA                                *
C       *  A2      = EXIT AREA                                    *
C       *  CQ1     = HEAT ADDITION COEFFICIENT                    *
C       *  CQ2     = HEAT ADDITION COEFFICIENT                    *
C       *  NPTS    = CAVITY INTEGRATION INCREMENTS                *
C       *                                                         *
C       *  OUTPUT VARIABLES:                                      *
C       *                                                         *
C       *  M2      = EXIT MACH NUMBER                             *
C       *  T2      = EXIT STATIC TEMPERATURE                      *
C       *  T02     = EXIT STAGNATION TEMPERATURE                  *
C       *  P2      = EXIT STATIC PRESSURE                         *
C       *  P02     = EXIT STAGNATION PRESSURE                     *
C       *  FAIL    = ERROR FLAG                                   *
C       *                                                         *
C       ***********************************************************
C
      SUBROUTINE CAVITY(G,M1,DUMMY1,DUMMY2,A1,A2,CQ1,CQ2,NPTS,
     -M2,T2,T02,P2,P02,FAIL)
C
      EXTERNAL FMSQD
      IMPLICIT REAL*4(L,M)
      DIMENSION T0(25)
      COMMON/FVD/ZI(3),XI(3),X(25),M(25),P(25),P0(25),T(25)
      COMMON/COEFF/X1,CA(2),CT0(2)
      DATA YES/'YES'/
C
C
```

```
C     ***********************************************************
C     *                                                         *
C     *          INITIALIZE VARIABLES AT STATION (1).           *
C     *                                                         *
C     ***********************************************************
C
C
      X1=DUMMY1
      X2=DUMMY2
      X(1)=X1
      M(1)=M1
      P(1)=1.0
      PO(1)=1.0
      T(1)=1.0
      TO(1)=1.0
      XRKI=X1
      YRKI=M1**2
C
C
C     ***********************************************************
C     *                                                         *
C     *  CALCULATE THE CAVITY AREA COEFFICIENTS.  A LINEAR      *
C     *  VARIATION WITH X IS ASSUMED.                           *
C     *                                                         *
C     ***********************************************************
C
C
      CA(1)=(A1*X2-A2*X1)/(X2-X1)
      CA(2)=(A2-A1)/(X2-X1)
C
C
C     ***********************************************************
C     *                                                         *
C     *  CALCULATE THE RATE OF HEAT ADDITION COEFFICIENTS.  A   *
C     *  LINEAR VARIATION OF RATE OF HEAT ADDITION WITH X IS    *
C     *  ASSUMED.                                               *
C     *                                                         *
C     ***********************************************************
C
C
      CTO(1)=(CQ1*X2-CQ2*X1)/(X2-X1)
      CTO(2)=(CQ2-CQ1)/(X2-X1)
C
C
C     ***********************************************************
C     *                                                         *
C     *         INITIALIZE FLOW VARIABLES FOR INTEGRATION.      *
C     *                                                         *
C     ***********************************************************
C
```

```
C                                                                       CAVITY 10100
      LNP=0.0                                                           CAVITY 10200
      LNPO=0.0                                                          CAVITY 10300
      LNT=0.0                                                           CAVITY 10400
C                                                                       CAVITY 10500
C                                                                       CAVITY 10600
C     ************************************************************      CAVITY 10700
C     *                                                          *      CAVITY 10800
C     *  SET INCREMENT SIZE FOR R-K AND SIMPSON INTEGRATIONS.    *      CAVITY 10900
C     *                                                          *      CAVITY 11000
C     ************************************************************      CAVITY 11100
C                                                                       CAVITY 11200
C                                                                       CAVITY 11300
      DX=(X2-X1)/FLOAT(NPTS-1)                                          CAVITY 11400
      DXRKI=DX/2.0                                                      CAVITY 11500
C                                                                       CAVITY 11600
C                                                                       CAVITY 11700
C     ************************************************************      CAVITY 11800
C     *                                                          *      CAVITY 11900
C     *                   INTEGRATION SECTION                    *      CAVITY 12000
C     *                                                          *      CAVITY 12100
C     ************************************************************      CAVITY 12200
C                                                                       CAVITY 12300
C                                                                       CAVITY 12400
      DO 60 I=2,NPTS                                                    CAVITY 12500
C                                                                       CAVITY 12600
C                                                                       CAVITY 12700
C     ************************************************************      CAVITY 12800
C     *                                                          *      CAVITY 12900
C     *        SET-UP FOR D(M**2)/DX INTEGRATION BY R-K.         *      CAVITY 13000
C     *                                                          *      CAVITY 13100
C     ************************************************************      CAVITY 13200
C                                                                       CAVITY 13300
C                                                                       CAVITY 13400
      ZI(1)=YRKI                                                        CAVITY 13500
      XI(1)=XRKI                                                        CAVITY 13600
      DO 50 J=1,2                                                       CAVITY 13700
C                                                                       CAVITY 13800
C                                                                       CAVITY 13900
C     ************************************************************      CAVITY 14000
C     *                                                          *      CAVITY 14100
C     *                INTEGRATE D(M**2)/DX BY R-K.              *      CAVITY 14200
C     *                                                          *      CAVITY 14300
C     ************************************************************      CAVITY 14400
C                                                                       CAVITY 14500
C                                                                       CAVITY 14600
      CALL RKI1(G,DXRKI,XRKI,YRKI,FMSQC,FAIL)                           CAVITY 14700
      IF(FAIL.EQ.YES) GO TO 110                                         CAVITY 14800
      XI(J+1)=XRKI                                                      CAVITY 14900
      ZI(J+1)=YRKI                                                      CAVITY 15000
```

7.5.1 CLGDSP (Cont.)


```
50    CONTINUE
C
C
C     **********************************************************
C     *                                                        *
C     *      INTEGRATE TO FIND P,PO,T BY SIMPSON'S RULE.       *
C     *                                                        *
C     **********************************************************
C
C
      CALL FVI(I,G,DX,LNF,LNFO,LNT)
C
C
C     **********************************************************
C     *                                                        *
C     *  EVALUATE THE STAGNATION TEMPERATURE RATIO BASED ON A  *
C     *  RATE OF HEAT ADDITION THAT IS ASSUMED TO BE A LINEAR  *
C     *  FUNCTION OF X.                                        *
C     *                                                        *
C     **********************************************************
C
C
      TO(I)=(1.0+CTO(1)*(X(I)-X1)+0.5*CTO(2)*
     -(X(I)**2-X1**2))
60    CONTINUE
      TO2=TO(NPTS)
      T2=T(NPTS)
      PO2=PO(NPTS)
      P2=P(NPTS)
      M2=M(NPTS)
110   END
```

7.5.1 CLGDSP (Cont.)

```
C       ***********************************************************
C       *                                                         *
C       *         RUNGE-KUTTA INTEGRATION SUBROUTINE (RKI1)       *
C       *                  (OF SUBROUTINE CAVITY)                 *
C       *                                                         *
C       ***********************************************************
C
C       ***********************************************************
C       *                                                         *
C       *  SUBROUTINE RKI1 PERFORMS A FOURTH-ORDER RUNGE-KUTTA    *
C       *  INTEGRATION OF A FIRST-ORDER DIFFERENTIAL EQUATION...  *
C       *  DY/DX=F(P.X.Y) WHERE P IS A PARAMETER. THE SUBROUTINE  *
C       *  IS SPECIALIZED FOR 1-D FLOW WITH AREA CHANGE AND HEAT  *
C       *  ADDITION.                                              *
C       *                                                         *
C       ***********************************************************
C
C
        SUBROUTINE RKI1(F.DX.X.Y.F.FAIL)
C
        DATA YES/'YES'/
C
        N=0
        C1=F(P.X.Y)*DX
        XRK=X+0.5*DX
        YRK=Y+0.5*C1
        GO TO 40
10      C2=F(P,XRK,YRK)*DX
        YRK=Y+0.5*C2
        GO TO 40
20      C3=F(P,XRK,YRK)*DX
        XRK=X+DX
        YRK=Y+C3
        GO TO 40
30      C4=F(P,XRK,YRK)*DX
        YRK=Y+(C1+2.0*(C2+C3)+C4)/6.0
40      IF((Y .GT. 1) .AND. (YRK .LE. 1)) GO TO 50
        IF((Y .LT. 1) .AND. (YRK .GE. 1)) GO TO 50
        N=N+1
        GO TO (10,20,30,70), N
C
C
C       ***********************************************************
C       *                                                         *
C       *  TRANSITIONS FROM SUBSONIC-TO-SUPERSONIC FLOW OR        *
C       *  SUPERSONIC-TO-SUBSONIC FLOW ARE NOT ALLOWED IN THIS    *
C       *  PROGRAM.                                               *
C       *                                                         *
C       ***********************************************************
C
```

7.5.1 CLGDSP (Cont.)

```
C                                                                       RKI1  05100
50    WRITE(5,6C)                                                       RKI1  05200
60    FORMAT(//,5X,'.....R-K INTEGRATION TERMINATED BECAUSE ',          RKI1  05300
     -'CHOKING WAS ENCCUNTERED.'/)                                      RKI1  05400
      FAIL=YES                                                          RKI1  05500
      RETURN                                                            RKI1  05600
70    Y=YRK                                                             RKI1  05700
      X=XRK                                                             RKI1  05800
      END                                                               RKI1  05900
```

7.5.1 CLGDSP (Cont.)

```
C     ****************************************************************
C     *                                                              *
C     *         FLOW VARIABLE INTEGRATION SUBROUTINE (FVI)           *
C     *                  (OF SUBROUTINE CAVITY)                      *
C     *                                                              *
C     ****************************************************************
C
C     ****************************************************************
C     *                                                              *
C     *  SUBROUTINE FVI PERFORMS AN INTEGRATION BY SIMPSON'S         *
C     *  RULE TO FIND THE FLOW VARIABLES (M,P,PO,T) ALONG THE        *
C     *  LASER CAVITY AS A FUNCTION OF X.  THE VARIABLES ARE         *
C     *  FOUND BY INTEGRATING EQUATIONS OF THE FORM...               *
C     *  DY/DX=F(G,Z(X),X).  REFERENCE: SHAPIRO, PAGE 231.           *
C     *                                                              *
C     *  ALL VARIABLES ARE NON-DIMENSIONALIZED WITH RESPECT TO       *
C     *  THE LASER CAVITY ENTRANCE CONDITIONS.                       *
C     *                                                              *
C     ****************************************************************
C
C
      SUBROUTINE FVI(I,G,DX,LNP,LNPO,LNT)
C
      IMPLICIT REAL*4(L,M)
      COMMON/FVD/ZI(3),XI(3),X(25),M(25),P(25),PO(25),T(25)
C
C     ****************************************************************
C     *                                                              *
C     *        FUNCTIONS TO BE INTEGRATED WHERE Z=M**2.              *
C     *                                                              *
C     ****************************************************************
C
C
      FP(G,Z,X)=(G*Z/(1.-Z))*(FA(X)-(1.+0.5*(G-1.)*Z)*FTO(X))
      FPO(G,Z,X)=-0.5*G*Z*FTO(X)
      FT(G,Z,X)=((G-1.0)*Z/(1.0-Z))*FA(X)
     -+((1.0-G*Z)*(1.0+0.5*(G-1.0)*Z)/(1.0-Z))*FTO(X)
C
C
C     ****************************************************************
C     *                                                              *
C     *               SIMPSON'S RULE INTEGRATION.                    *
C     *                                                              *
C     ****************************************************************
C
C
      DLNP=(DX/6.0)*(FP(G,ZI(1),XI(1))+4.0*FP(G,ZI(2),XI(2))
     -+FP(G,ZI(3),XI(3)))
      DLNT=(DX/6.0)*(FT(G,ZI(1),XI(1))+4.0*FT(G,ZI(2),XI(2))
```

7.5.1 CLGDSP (Cont.)

```
     -+FT(G,ZI(3),XI(3)))
      DLNPO=(DX/6.0)*(FPO(G,ZI(1),XI(1))+4.0*FPO(G,ZI(2),XI(2))
     -+FPO(G,ZI(3),XI(3)))
C
C
C     ************************************************************
C     *                                                          *
C     *    FIND THE NEW VALUES OF THE INTEGRATION VARIABLES.     *
C     *                                                          *
C     ************************************************************
C
C
      LNP=LNP+DLNP
      LNPO=LNPO+DLNPO
      LNT=LNT+DLNT
C
C
C     ************************************************************
C     *                                                          *
C     *   LASER CAV'TY FLOW VARIABLES...V(I)-VS-X(I), I=1,NPTS.  *
C     *                                                          *
C     ************************************************************
C
C
      X(I)=XI(3)
      P(I)=EXP(LNP)
      PO(I)=EXP(LNPO)
      T(I)=EXP(LNT)
      M(I)=SQRT(ZI(3))
      END
```

```
C     ************************************************************
C     *                                                          *
C     *                   FUNCTION SUBPROGRAMS                   *
C     *                 (OF SUBROUTINE CAVITY)                   *
C     *                                                          *
C     ************************************************************
C
C     ************************************************************
C     *                                                          *
C     *          NOTE...Y=M**2 AND DY/DX=FMSQD(G,X,Y)            *
C     *                                                          *
C     ************************************************************
C
C
      FUNCTION FMSQD(G,X,Y)
      FMSQD=(Y*(1.0+0.5*(G-1.0)*Y)/(1.0-Y))*
     -(-2.0*FA(X)+(1.0+G*Y)*FTO(X))
      END
C
C
C     ************************************************************
C     *                                                          *
C     *  FUNCTION FOR EVALUATING...(1.0/A)(DA/DX).  THE LASER    *
C     *  CAVITY AREA IS ASSUMED TO BE A LINEAR FUNCTION OF X.    *
C     *                                                          *
C     ************************************************************
C
C
      FUNCTION FA(X)
      COMMON/COEFF/X1,CA(2),CTO(2)
      FA=CA(2)/(CA(1)+CA(2)*X)
      END
C
C
C     ************************************************************
C     *                                                          *
C     *  FUNCTION FOR EVALUATING...(1.0/TO)(DTO/DX).  THE RATE   *
C     *  OF HEAT ADDITION IS ASSUMED TO BE A LINEAR FUNCTION     *
C     *  OF X.                                                   *
C     *                                                          *
C     ************************************************************
C
C
      FUNCTION FTO(X)
      COMMON/COEFF/X1,CA(2),CTO(2)
      FTO=(CTO(1)+CTO(2)*X)/(1.0+CTO(1)*(X-X1)+0.5*CTO(2)*
     -(X**2-X1**2))
      END
```

```
C       ************************************************************
C       *                                                          *
C       *       NORMAL SHOCK DIFFUSER SUBROUTINE (NSDS)            *
C       *                                                          *
C       ************************************************************
C
C       ************************************************************
C       *                                                          *
C       *  SUBROUTINE NSDS CALCULATES THE PRESSURE RATIO ACROSS    *
C       *  A CONSTANT-AREA, SUPERSONIC DIFFUSER.  THE STATIC       *
C       *  PRESSURE RATIO IS TAKEN AS RD*(PY/PX) FOR A NORMAL      *
C       *  SHOCK AT THE ENTERING MACH NO.  ALL OTHER PROPERTIES    *
C       *  ARE CALCULATED FROM THE ISENTROPIC FLOW RELATIONS TO    *
C       *  BE CONSISTENT WITH THE ENTRANCE AND EXIT MACH NO.S.     *
C       *                                                          *
C       * INPUT VARIABLES:                                         *
C       *                                                          *
C       * G      = GAMMA                                           *
C       * M1     = ENTRANCE MACH NUMBER                            *
C       * RD     = NORMAL SHOCK DIFFUSER COEFFICIENT               *
C       *                                                          *
C       * OUTPUT VARIABLES:                                        *
C       *                                                          *
C       * M2     = EXIT MACH NUMBER                                *
C       * P2P1   = EXIT-TO-ENTRANCE STATIC PRESSURE RATIO          *
C       * P20P10 = EXIT-TO-ENTRANCE STAGNATION PRESSURE RATIO      *
C       * T2T1   = EXIT-TO-ENTRANCE STATIC TEMPERATURE RATIO       *
C       * T20T10 = EXIT-TO-ENTRANCE STAGNATION TEMPERATURE RATIO   *
C       *                                                          *
C       ************************************************************
C
C
        SUBROUTINE NSDS(G,M1,RD,M2,P2P1,P20P10,T2T1,T20T10)
C
        IMPLICIT REAL*4(M)
C
        TOTM(GX,MX)=1.0+0.5*(GX-1.0)*MX*MX
        POPM(GX,MX)=(1.0+0.5*(GX-1.0)*MX*MX)**(GX/(GX-1.0))
C
        M2=SQRT((2.0+(G-1.0)*M1*M1)/(2.0*G*M1*M1-G+1.0))
        P2P1=RD*(2.0*G*M1*M1-G+1.0)/(G+1.0)
        P10P1=POPM(G,M1)
        P20P2=POPM(G,M2)
        P20P10=P20P2*P2P1/P10P1
        T20T10=1.0
        T10T1=TOTM(G,M1)
        T20T2=TOTM(G,M2)
        T2T1=T10T1*T20T10/T20T2
        END
```

```
C     **************************************************************  SDS 00100
C     *                                                            *  SDS 00200
C     *            SUBSONIC DIFFUSER SUBROUTINE (SDS)              *  SDS 00300
C     *                                                            *  SDS 00400
C     **************************************************************  SDS 00500
C                                                                     SDS 00600
C     **************************************************************  SDS 00700
C     *                                                            *  SDS 00800
C     *  SUBROUTINE SDS CALCULATES THE PRESSURE RATIO ACROSS A     *  SDS 00900
C     *  CONICAL, SUBSONIC DIFFUSER WITH AN INCLUDED ANGLE OF      *  SDS 01000
C     *  15 DEGREES.  THE STATIC PRESSURE RATIO IS COMPUTED        *  SDS 01100
C     *  USING AN EMPERICAL DIFFUSER EFFICIENCY.  ALL OTHER        *  SDS 01200
C     *  PROPERTIES ARE CALCULATED FROM THE ISENTROPIC FLOW        *  SDS 01300
C     *  RELATIONS TO BE CONSISTENT WITH THE ENTRANCE AND EXIT     *  SDS 01400
C     *  MACH NO.S.                                                *  SDS 01500
C     *                                                            *  SDS 01600
C     *  THE SUBSONIC DIFFUSER EFFICIENCY GIVEN BY:                *  SDS 01700
C     *                                                            *  SDS 01800
C     *                 EFF=(P2'-P1)/(P2-P1)                       *  SDS 01900
C     *                                                            *  SDS 02000
C     *  IS LIMITED TO THE RANGE: 0.2<M1<0.5, 2.34<A2/A1<5.2       *  SDS 02100
C     *  AND IS DERIVED FROM DATA IN THE FOLLOWING REFERENCES:     *  SDS 02200
C     *                                                            *  SDS 02300
C     *  HENRY,J.R., WOOD,C.C., AND WILBUR,S.W., "SUMMARY OF       *  SDS 02400
C     *  SUBSONIC-DIFFUSER DATA," NACA RM L56F05 (1956).           *  SDS 02500
C     *                                                            *  SDS 02600
C     *  PATTERSON,G.N., "MODERN DIFFUSER DESIGN," AIRCRAFT        *  SDS 02700
C     *  ENGINEERING, 9(9):267-273 (1938).                         *  SDS 02800
C     *                                                            *  SDS 02900
C     *  THE SUBSONIC DIFFUSER COEFFICIENT IS DEFINED AS:          *  SDS 03000
C     *                                                            *  SDS 03100
C     *                 RD=(P2'/P1)/(P2/P1)                        *  SDS 03200
C     *                                                            *  SDS 03300
C     * INPUT VARIABLES:                                           *  SDS 03400
C     *                                                            *  SDS 03500
C     * G      = GAMMA                                             *  SDS 03600
C     * M1     = ENTRANCE MACH NUMBER                              *  SDS 03700
C     * A2A1   = EXIT-TO-ENTRANCE AREA RATIO                       *  SDS 03800
C     *                                                            *  SDS 03900
C     * OUTPUT VARIABLES:                                          *  SDS 04000
C     *                                                            *  SDS 04100
C     * M2     = EXIT MACH NUMBER                                  *  SDS 04200
C     * P2P1   = EXIT-TO-ENTRANCE STATIC PRESSURE RATIO            *  SDS 04300
C     * P20P10 = EXIT-TO-ENTRANCE STAGNATION PRESSURE RATIO        *  SDS 04400
C     * T2T1   = EXIT-TO-ENTRANCE STATIC TEMPERATURE RATIO         *  SDS 04500
C     * T20T10 = EXIT-TO-ENTRANCE STAGNATION TEMPERATURE RATIO     *  SDS 04600
C     * RD     = SUBSONIC DIFFUSER COEFFICIENT                     *  SDS 04700
C     * FAIL   = ERROR FLAG                                        *  SDS 04800
C     *                                                            *  SDS 04900
C     **************************************************************  SDS 05000
```

7.5.1 CLGDSP (Cont.)

```
C
C
      SUBROUTINE SDS(G,M1,A2A1,M2,P2P1,P20P10,T2T1,T20T10,RD,
     -FAIL)
C
      IMPLICIT REAL*4(M)
      DATA YES/'YES'/,SUB/'SUB'/
C
C
C     ***********************************************************
C     *                                                         *
C     *                 GAS DYNAMIC FUNCTIONS                   *
C     *                                                         *
C     ***********************************************************
C
C
      TOTM(GX,MX)=1.0+0.5*(GX-1.0)*MX*MX
      POPM(GX,MX)=(1.0+0.5*(GX-1.0)*MX*MX)**(GX/(GX-1.0))
C
C
C     ***********************************************************
C     *                                                         *
C     *      CALCULATIONS FOR CONSTANT-AREA DIFFUSER            *
C     *                                                         *
C     ***********************************************************
C
C
      IF(A2A1.NE.1.0) GO TO 1
      M2=M1
      P2P1=1.0
      P20P10=1.0
      T2T1=1.0
      T20T10=1.0
      RD=1.0
      RETURN
C
C
C     ***********************************************************
C     *                                                         *
C     *                  CALCULATE CONSTANTS                    *
C     *                                                         *
C     ***********************************************************
C
C
1     G2=2.0/(G+1.0)
      G4=(G+1.0)/(2.0*(G-1.0))
C
C
C     ***********************************************************
C     *                                                         *
```

```
C     *                    SOLVE A2A2S FOR M2                          *
C     *                                                                *
C     ******************************************************************
C
C
      A1A1S=(1.0/M1)*(G2*TOTM(G,M1))**G4
      A2A2S=A2A1*A1A1S
      CALL MAAS(G,M1,A2A2S,SUB,5.0E-06,M2,FAIL)
      IF(FAIL.EQ.YES) RETURN
C
C
C     ******************************************************************
C     *                                                                *
C     *              CALCULATE THE DIFFUSER EFFICIENCY                 *
C     *                                                                *
C     ******************************************************************
C
C
      EFF=0.002685*A2A1*A2A1*A2A1-0.024461*A2A1*A2A1-0.027229*
     -A2A1+1.048992
C
C
C     ******************************************************************
C     *                                                                *
C     *         CALCULATE THE IDEAL STATIC PRESSURE RATIO              *
C     *                                                                *
C     ******************************************************************
C
C
      P10P1=POPM(G,M1)
      P20P2=POPM(G,M2)
      P2P1=P10P1/P20P2
      RD=EFF+(1.0-EFF)/P2P1
C
C
C     ******************************************************************
C     *                                                                *
C     *         CALCULATE THE ACTUAL STATIC PRESSURE RATIO             *
C     *                                                                *
C     ******************************************************************
C
C
      P2P1=RD*P2P1
      P20P10=P20P2*P2P1/P10P1
      T20T10=1.0
      T10T1=TOTM(G,M1)
      T20T2=TOTM(G,M2)
      T2T1=T10T1*T20T10/T20T2
      END
```

```
C     ************************************************************
C     *                                                          *
C     *       CCNSTANT-PRESSURE EJECTOR SUBROUTINE (CPES)        *
C     *                                                          *
C     ************************************************************
C
C     ************************************************************
C     *                                                          *
C     *  SUBROUTINE CPES CALCULATES THE COMPRESSION RATIO FOR    *
C     *  A CCNSTANT-PRESSURE, SUBSONIC-SUPERSONIC EJECTOR WITH   *
C     *  A CCNSTANT-AREA DIFFUSER SECTION BY A ONE-DIMENSIONAL   *
C     *  ANALYSIS.                                               *
C     *                                                          *
C     *  INPUT VARIABLES:                                        *
C     *                                                          *
C     *  GS      = SECONDARY GAMMA                               *
C     *  GP      = PRIMARY GAMMA                                 *
C     *  MWSP    = SECONDARY-TO-PRIMARY MOLECULAR WEIGHT RATIO   *
C     *  TSOPO   = SECONDARY-TO-PRIMARY STAGNATION TEMPERATURE   *
C     *            RATIO                                         *
C     *  WSPI    = SECONDARY-TO-PRIMARY MASS FLOW RATIO          *
C     *  MP1     = PRIMARY MACH NO. AT THE MIXING TUBE ENTRANCE  *
C     *  AM2P1   = PRIMARY-TO-MIXING TUBE MINIMUM AREA RATIO     *
C     *  RD      = NORMAL SHOCK DIFFUSER COEFFICIENT             *
C     *                                                          *
C     *  OUTPUT VARIABLES:                                       *
C     *                                                          *
C     *  MS1     = SECONDARY MACH NO. AT THE MIXING TUBE         *
C     *            ENTRANCE                                      *
C     *  ASIP1   = SECONDARY-TO-PRIMARY AREA RATIO AT THE        *
C     *            MIXING TUBE ENTRANCE                          *
C     *  GM      = MIXED STREAM GAMMA                            *
C     *  MWMP    = MIXED STREAM-TO-PRIMARY MOLECULAR WEIGHT      *
C     *            RATIO                                         *
C     *  TMOPO   = MIXED STREAM-TO-PRIMARY STAGNATION            *
C     *            TEMPERATURE RATIO                             *
C     *  MM3     = MIXED STREAM MACH NO. AT THE MIXING TUBE      *
C     *            EXIT                                          *
C     *  PPOSO   = PRIMARY-TO-SECONDARY STAGNATION PRESSURE      *
C     *            RATIO                                         *
C     *  PM3SO   = MIXED STREAM STATIC-TO-SECONDARY STAGNATION   *
C     *            PRESSURE RATIO                                *
C     *  FAIL    = ERROR FLAG                                    *
C     *                                                          *
C     ************************************************************
C
C
      SUBRCUTINE CPES(GS,GP,MWSP,TSOPO,WSPI,MP1,AM2P1,RD,MS1,
     -ASIP1,GM,MWMP,TMOPO,MM3,PPOSO,PM3SO,FAIL)
C
```

```
      IMPLICIT REAL*4(M)
      DATA YES/'YES'/
C
C
C     ***********************************************************
C     *                                                         *
C     *                  GAS DYNAMIC FUNCTIONS                  *
C     *                                                         *
C     ***********************************************************
C
C
      WM(G,M)=M*SQRT(G*(1.+0.5*(G-1.)*(M**2)))
      PPOM(G,M)=(1.+0.5*(G-1.)*(M**2))**(-G/(G-1.))
      PYXMX(G,MX)=(2.*G/(G+1.))*(MX**2)-((G-1.)/(G+1.))
      MYXMX(G,MX)=SQRT((2.0+(G-1.0)*MX*MX)/(2.0*G*MX*MX-G+1.0))
C
C
C     ***********************************************************
C     *                                                         *
C     *     CALCULATE THE MIXED-GAS PROPERTIES AT SECTION 3.    *
C     *                                                         *
C     ***********************************************************
C
C
      MWMP=(1.+WSPI)/(1.+(WSPI/MWSP))
      CPSP=(GS/GP)*((GP-1.)/(GS-1.))/MWSP
      GM=1./(1.-((GP-1.)/GP)*((1.+(WSPI/MWSP))/(1.+CPSP*WSPI)))
      CPMP=(1.+WSPI*CPSP)/(1.+WSPI)
C
C
C     ***********************************************************
C     *                                                         *
C     *  CALCULATE THE STAGNATION TEMPERATURE RATIO: TMO/TPO.   *
C     *                                                         *
C     ***********************************************************
C
C
      TMOPO=(1.+WSPI*CPSP*TSOPO)/(1.+WSPI*CPSP)
C
C
C     ***********************************************************
C     *                                                         *
C     *      CALCULATE C-P EJECTOR SOLUTION, MM2,MS1,ASIP1.     *
C     *                                                         *
C     ***********************************************************
C
C
      CO=(1.+WSPI)*SQRT(TMOPO/MWMP)*WM(GP,MP1)
C
C
```

7.5.1 CLGDSP (Cont.)

```
C     ****************************************************************  CPES
C     *                                                              *  CPES
C     *  CHECK INPUT VALUE OF "AM2P1" FOR CONSISTENCY WITH           *  CPES
C     *  OTHER DATA FOR SOLUTIONS TO EXIST.                          *  CPES
C     *                                                              *  CPES
C     ****************************************************************  CPES
C                                                                       CPES
C                                                                       CPES
      AMAX=((C0**2)/(GP*(MP1**2))-0.5*(((GM-1.0)/GM)*                   CPES
     -GP*(MP1**2)))                                                     CPES
      IF(AM2P1 .GT. AMAX) GO TO 120                                     CPES
      C1=C0/AM2P1                                                       CPES
      MM2=SQRT((SQRT(GM**2+2.*GM*(GM-1.)*(C1**2))-GM)/                  CPES
     -(GM*(GM-1.0)))                                                    CPES
      IF(MM2 .LT. 1.0) GO TO 60                                         CPES
      D2=(AM2P1*GM*(MM2**2)-GP*(MP1**2))                                CPES
      IF(D2 .LE. 0.0) GO TO 80                                          CPES
      C2=WSPI*SQRT(TSOPO/MWSP)*WM(GP,MP1)/D2                            CPES
      MS1=SQRT(2./(1.0+(2.0*(C2**2)-1.0)*GS))                           CPES
      ASIP1=D2/(GS*(MS1**2))                                            CPES
C                                                                       CPES
C                                                                       CPES
C     ****************************************************************  CPES
C     *                                                              *  CPES
C     *           CALCULATE THE VARIOUS PRESSURE RATIOS.             *  CPES
C     *                                                              *  CPES
C     ****************************************************************  CPES
C                                                                       CPES
C                                                                       CPES
      PPOSO=PPOM(GS,MS1)/PPOM(GP,MP1)                                   CPES
      PM2SO=PPOM(GS,MS1)                                                CPES
C                                                                       CPES
C                                                                       CPES
C     ****************************************************************  CPES
C     *                                                              *  CPES
C     *  FOR A DIFFUSER BASED ON A NORMAL SHOCK AT MX=MM2. THE       *  CPES
C     *  OVERALL EJECTOR PRESSURE RISE IS PM3SO.                     *  CPES
C     *                                                              *  CPES
C     ****************************************************************  CPES
C                                                                       CPES
C                                                                       CPES
      PM3SO=PM2SO*RD*PYXMX(GM,MM2)                                      CPES
      MM3=MYXMX(GM,MM2)                                                 CPES
      IF(MS1.GT.1.0) GO TO 100                                          CPES
      RETURN                                                            CPES
C                                                                       CPES
C                                                                       CPES
C     ****************************************************************  CPES
C     *                                                              *  CPES
C     *                       ERROR MESSAGES                         *  CPES
```

7.5.1 CLGDSP (Cont.)

```
C      *                                                                *   CPES
C      ******************************************************************   CPES
C                                                                           CPES
C                                                                           CPES
60     WRITE(5,70)                                                          CPES
70     FORMAT(5X,'......ERROR: SUBSONIC FLOW AT SECTION 2.'//)              CPES
       GO TO 140                                                            CPES
80     WRITE(5,90)                                                          CPES
90     FORMAT(5X,'.....ERROR: IMPOSSIBLE VALUE OF MS1.'//)                  CPES
       GO TO 140                                                            CPES
100    WRITE(5,110)                                                         CPES
110    FORMAT(5X,'.....NOTE: MS1 IS SUPERSONIC.'//)                         CPES
       GO TO 140                                                            CPES
120    WRITE(5,130) AMAX                                                    CPES
130    FORMAT(5X,'.....ERROR: AM2P1 >',F7.3,2X,'WAS INPUT.',/,              CPES
      -10X,'THIS VALUE OF AM2P1 IS INCONSISTENT WITH THE',/,                CPES
      -10X,'REMAINDER OF THE INPUT DATA.'//)                                CPES
140    FAIL=YES                                                             CPES
       END                                                                  CPES
```

7.5.1 CLGDSP (Cont.)

```
C     ***************************************************************     CAES
C     *                                                             *     CAES
C     *        CONSTANT-AREA EJECTOR SUBROUTINE (CAES)              *     CAES
C     *                                                             *     CAES
C     ***************************************************************     CAES
C                                                                         CAES
C     ***************************************************************     CAES
C     *                                                             *     CAES
C     *  SUBROUTINE CAES CALCULATES THE BREAK-OFF COMPRESSION       *     CAES
C     *  RATIO FOR A CONSTANT-AREA, SUBSONIC-SUPERSONIC             *     CAES
C     *  EJECTOR BY A ONE-DIMENSIONAL ANALYSIS.                     *     CAES
C     *                                                             *     CAES
C     *  PPOSO-VS-PM3SO AND OTHER EJECTOR CHARACTERISTICS ARE       *     CAES
C     *  CALCULATED FOR WSP=WSPI IN THE SUPERSONIC REGIME (SR)      *     CAES
C     *  OR THE SATURATED-SUPERSONIC REGIME (SSR).  THE             *     CAES
C     *  ASSUMPTION IS MADE THAT MP1 REMAINS AT ITS DESIGN          *     CAES
C     *  VALUE.  (MR) IS THE MIXED REGIME.                          *     CAES
C     *                                                             *     CAES
C     *  INPUT VARIABLES:                                           *     CAES
C     *                                                             *     CAES
C     *  GS     = SECONDARY GAMMA                                   *     CAES
C     *  GP     = PRIMARY GAMMA                                     *     CAES
C     *  MWSP   = SECONDARY-TO-PRIMARY MOLECULAR WEIGHT RATIO       *     CAES
C     *  TSOPO  = SECONDARY-TO-PRIMARY STAGNATION TEMPERATURE       *     CAES
C     *           RATIO                                             *     CAES
C     *  WSPI   = SECONDARY-TO-PRIMARY MASS FLOW RATIO              *     CAES
C     *  MP1    = PRIMARY MACH NO. AT THE MIXING TUBE ENTRANCE      *     CAES
C     *  AP1M3  = PRIMARY-TO-MIXING TUBE AREA RATIO                 *     CAES
C     *                                                             *     CAES
C     *  OUTPUT VARIABLES:                                          *     CAES
C     *                                                             *     CAES
C     *  MS1    = SECONDARY MACH NO. AT THE MIXING TUBE             *     CAES
C     *           ENTRANCE                                          *     CAES
C     *  GM     = MIXED STREAM GAMMA                                *     CAES
C     *  MWMP   = MIXED STREAM-TO-PRIMARY MOLECULAR WEIGHT          *     CAES
C     *           RATIO                                             *     CAES
C     *  TMOPO  = MIXED STREAM-TO-PRIMARY STAGNATION                *     CAES
C     *           TEMPERATURE RATIO                                 *     CAES
C     *  MM3    = MIXED STREAM MACH NO. AT THE MIXING TUBE          *     CAES
C     *           EXIT                                              *     CAES
C     *  PPOSO  = PRIMARY-TO-SECONDARY STAGNATION PRESSURE          *     CAES
C     *           RATIO                                             *     CAES
C     *  PM3SO  = MIXED STREAM STATIC-TO-SECONDARY STAGNATION       *     CAES
C     *           PRESSURE RATIO                                    *     CAES
C     *  FAIL   = ERROR FLAG                                        *     CAES
C     *                                                             *     CAES
C     ***************************************************************     CAES
C                                                                         CAES
C                                                                         CAES
      SUBROUTINE CAES(GS,GP,MWSP,TSOPO,WSPI,MP1,AP1M3,MS1,GM,             CAES
```

7.5.1 CLGDSP (Cont.)

```
     -MWMP,TMOPC,MM3,PPCSO,PM3SO,FAIL)
C
      IMPLICIT REAL*4(M)
C
C
C     ****************************************************
C     *                                                  *
C     *              GAS DYNAMIC FUNCTIONS               *
C     *                                                  *
C     ****************************************************
C
C
      WM(G,M)=M*SQRT(G*(1.0+0.5*(G-1.0)*M*M))
      PYXMX(G,MX)=(2.*G/(G+1.))*(MX**2)-((G-1.)/(G+1.))
C
C
C     ****************************************************
C     *                                                  *
C     *  INITIALIZE THE VARIABLES FOR THE ITERATION TO FIND  *
C     *  THE BREAK-OFF VALUE OF MS1, MS1B.               *
C     *                                                  *
C     ****************************************************
C
C
      DATA DMS1B,MS1BL/0.1,1.0E-03/,YES/'YES'/
      DATA ERRMS1,ERRORY,NITMAX/2*5.0E-06,100/
C
C
C     **         ******************************************
C     *                                                  *
C     *        LIMIT, PS1P1U, IS BASED ON A NORMAL SHOCK *
C     *  STANDING AT THE PRIMARY NOZZLE EXIT WITH: MX=MP1.  *
C     *                                                  *
C     ****************************************************
C
C
      PS1P1U=PYXMX(GF,MP1)
C
C
C     ****************************************************
C     *                                                  *
C     *  AT THE JUNCTURE (J) BETWEEN THE (SR) AND THE (SSR)  *
C     *  THE VARIABLES ARE: (MS1=1.0, PS1P1=1.0, MP1=MP1,    *
C     *  WSP=WSFJ).                                      *
C     *                                                  *
C     ****************************************************
C
C
      AS1P1=((1.0/AP1M3)-1.0)
      CONST=SQRT(MWSP/TSOPC)*AS1P1/WM(CP,MP1)
```

```
      WSPJ=CCNST*WM(GS,1.0)                                              CAES  10100
C                                                                        CAES  10200
C                                                                        CAES  10300
C     ********************************************************          CAES  10400
C     *                                                      *          CAES  10500
C     *  DETERMINE WHETHER THE OPERATING REGIME IS (SR) OR   *          CAES  10600
C     *  (SSR).                                              *          CAES  10700
C     *                                                      *          CAES  10800
C     ********************************************************          CAES  10900
C                                                                        CAES  11000
C                                                                        CAES  11100
      IF(WSPI.LT.WSPJ) GO TO 20                                          CAES  11200
C                                                                        CAES  11300
C                                                                        CAES  11400
C     ********************************************************          CAES  11500
C     *                                                      *          CAES  11600
C     * FOR THE BREAK-OFF POINT (B) BETWEEN THE (SSR) AND (MR) *        CAES  11700
C     *                                                      *          CAES  11800
C     ********************************************************          CAES  11900
C                                                                        CAES  12000
C                                                                        CAES  12100
      MS1B=1.0                                                           CAES  12200
      PS1P1B=WSPI/WSPJ                                                   CAES  12300
      IF(PS1P1E.GE.PS1P1U       . 70                                     CAES  12400
      GO TC 40                                                           CAES  12500
C                                                                        CAES  12600
C                                                                        CAES  12700
C     ********************************************************          CAES  12800
C     *                                                      *          CAES  12900
C     *  DETERMINE THE BREAK-OFF POINT (B) BETWEEN (SR) AND  *          CAES  13000
C     *  (MR).  INITIALIZE THE VARIABLES FOR THE ITERATION TO *         CAES  13100
C     *  FIND (MS1B,PS1P1B) IN (SSR).                        *          CAES  13200
C     *                                                      *          CAES  13300
C     ********************************************************          CAES  13400
C                                                                        CAES  13500
C                                                                        CAES  13600
20    NIT=1                                                              CAES  13700
      NTYPE=1                                                            CAES  13800
C                                                                        CAES  13900
C                                                                        CAES  14000
C     ********************************************************          CAES  14100
C     *                                                      *          CAES  14200
C     *  INITIALIZE THE ITERATION TC FIND (MS1B) SOLUTION IN  *         CAES  14300
C     *  (SR).  THE SOLUTICN IS BASED CN FABRI'S CRITERION.  *          CAES  14400
C     *                                                      *          CAES  14500
C     ********************************************************          CAES  14600
C                                                                        CAES  14700
C                                                                        CAES  14800
      MS1B=MS1BL                                                         CAES  14900
30    CALL CAEFC(GS,GP,MS1B,MP1,AP1M3,PS1P1B,NTYPE,FAIL)                 CAES  15000
```

7.5.1 CLGDSP (Cont.)

```
      IF(FAIL.EQ.YES) RETURN                                            CAES
      IF(NTYPE.EQ.3) GO TO 32                                           CAES
      WSPB=CCNST*PS1P1B*WM(GS,MS1B)                                     CAES
      CALL ITER(MS1B,DMS1B,ERRMS1,+1.0,WSPB,WSPI,ERRORY,NIT,            CAES
     -NTYPE,XNEG,YNEG,XPOS,YPOS,NSIGN1,NSIGN2)                          CAES
      IF(MS1B.GT.1.0) MS1B=1.0                                          CAES
      IF(NIT.GT.NITMAX) GO TO 100                                       CAES
      GO TO(30,30,40),NTYPE                                             CAES
C                                                                       CAES
C                                                                       CAES
C     ***************************************************************** CAES
C     *                                                               * CAES
C     *         APPROXIMATE SOLUTION WITH (PS1P1B=1) FOUND.           * CAES
C     *                                                               * CAES
C     ***************************************************************** CAES
C                                                                       CAES
C                                                                       CAES
32    A=(WSPI/(CCNST*PS1P1B))**2                                        CAES
      MS1B=SQRT((1./(GS-1.))*(SQRT(1.+(2.*(GS-1.)/GS)*A)-1.))           CAES
C                                                                       CAES
C                                                                       CAES
C     ***************************************************************** CAES
C     *                                                               * CAES
C     *         DETERMINE THE REMAINING VARIABLES AT (B).             * CAES
C     *                                                               * CAES
C     ***************************************************************** CAES
C                                                                       CAES
C                                                                       CAES
40    MS1=MS1B                                                          CAES
      PS1P1=PS1P1B                                                      CAES
C                                                                       CAES
C                                                                       CAES
C     ***************************************************************** CAES
C     *                                                               * CAES
C     *  CALCULATE THE DOWNSTREAM CONDITIONS FOR THE BREAK-OFF        * CAES
C     *  POINT.                                                       * CAES
C     *                                                               * CAES
C     ***************************************************************** CAES
C                                                                       CAES
C                                                                       CAES
      CALL CAECCV(GS,GF,MWSP,TSOPO,MS1,MP1,AP1M3,PS1P1,GM,MWMP,         CAES
     -TMOPO,MM3,PPOSO,PM3SO,FAIL)                                       CAES
      IF(FAIL.EQ.YES) GO TO 80                                          CAES
      RETURN                                                            CAES
C                                                                       CAES
C                                                                       CAES
C     ***************************************************************** CAES
C     *                                                               * CAES
C     *                    ERROR MESSAGES                             * CAES
C     *                                                               * CAES
```

7.5.1 CLGDSP (Cont.)

```
C     *****************************************************     CAES  20100
C                                                                CAES  20200
C                                                                CAES  20300
70    WRITE(5,72)                                                CAES  20400
72    FORMAT(/,5X,'...ERROR IN CAES:(PS1P1B.GE.PS1P1U).')        CAES  20500
      GO TC 12C                                                  CAES  20600
80    WRITE(5,90)                                                CAES  20700
90    FORMAT(/,5X,'...ERROR CCCURED IN (CAEOCV).',/)             CAES  20800
      GO TC 120                                                  CAES  20900
100   WRITE(5,11C)                                               CAES  21000
11C   FORMAT(/,5X,'...NCN-CCNVERGENCE OF ITERATIONS FOR',/,      CAES  21100
     -5X,'(MS1B,PS1P1B) IN (SR) IN (CAES).',/)                   CAES  21200
120   FAIL=YES                                                   CAES  21300
      END                                                        CAES  21400
```

```
C     ***********************************************************     CAEFC 00100
C     *                                                         *     CAEFC 00200
C     *                 CONSTANT-AREA EJECTOR                   *     CAEFC 00300
C     *           FABRI CRITERION SUBROUTINE (CAEFC)            *     CAEFC 00400
C     *                 (OF SUBROUTINE CAES)                    *     CAEFC 00500
C     *                                                         *     CAEFC 00600
C     ***********************************************************     CAEFC 00700
C                                                                     CAEFC 00800
C     ***********************************************************     CAEFC 00900
C     *                                                         *     CAEFC 01000
C     *  SUBROUTINE CAEFC PERFORMS THE CONSTANT-AREA EJECTOR,   *     CAEFC 01100
C     *  FABRI CRITERION CALCULATIONS BY 1-D ANALYSIS FOR A     *     CAEFC 01200
C     *  SUPERSONIC PRIMARY (MP1>1) AND A SUBSONIC SECONDARY    *     CAEFC 01300
C     *  (MS1<1) WHICH CHOKES IN THE EJECTOR SHROUD (MS2=1).    *     CAEFC 01400
C     *  THIS EJECTOR ANALYSIS IS BASED ON THE CONSTANT-AREA    *     CAEFC 01500
C     *  SHROUD, EJECTOR ANALYSIS OF FABRI.  REFERENCE:         *     CAEFC 01600
C     *  NACA TM 1410.                                          *     CAEFC 01700
C     *                                                         *     CAEFC 01800
C     *  INPUT VARIABLES:                                       *     CAEFC 01900
C     *                                                         *     CAEFC 02000
C     *  GS     = SECONDARY GAMMA                               *     CAEFC 02100
C     *  GP     = PRIMARY GAMMA                                 *     CAEFC 02200
C     *  MS1    = SECONDARY MACH NO. AT THE MIXING TUBE         *     CAEFC 02300
C     *           ENTRANCE                                      *     CAEFC 02400
C     *  MP1    = PRIMARY MACH NO. AT THE MIXING TUBE ENTRANCE *     CAEFC 02500
C     *  AP1M3  = PRIMARY-TO-MIXING TUBE AREA RATIO             *     CAEFC 02600
C     *                                                         *     CAEFC 02700
C     *  OUTPUT VARIABLES:                                      *     CAEFC 02800
C     *                                                         *     CAEFC 02900
C     *  PS1P1  = SECONDARY-TO-PRIMARY STATIC PRESSURE RATIO    *     CAEFC 03000
C     *  NTYPE  = ITERATION CONTROL VARIABLE                    *     CAEFC 03100
C     *  FAIL   = ERROR FLAG                                    *     CAEFC 03200
C     *                                                         *     CAEFC 03300
C     ***********************************************************     CAEFC 03400
C                                                                     CAEFC 03500
C                                                                     CAEFC 03600
      SUBROUTINE CAEFC(GS,GP,MS1,MP1,AP1M3,PS1P1,NTYPE,FAIL)          CAEFC 03700
C                                                                     CAEFC 03800
      IMPLICIT REAL*4(M)                                              CAEFC 03900
      DATA YES/'YES'/,SUP/'SUP'/                                      CAEFC 04000
C                                                                     CAEFC 04100
C                                                                     CAEFC 04200
C     ***********************************************************     CAEFC 04300
C     *                                                         *     CAEFC 04400
C     *                 GAS DYNAMIC FUNCTIONS                   *     CAEFC 04500
C     *                                                         *     CAEFC 04600
C     ***********************************************************     CAEFC 04700
C                                                                     CAEFC 04800
C                                                                     CAEFC 04900
      PPOM(G,M)=(1.+.5*(G-1.)*(M**2))**(-G/(G-1.))                    CAEFC 05000
```

7.5.1 CLGDSP (Cont.)

```
      AASM(G,M)=(1./M)*(((2./(G+1.))*(1.+0.5*(G-1.)*(M**2)))
     -**(0.5*(G+1.)/(G-1.)))
      MMS(G,MS)=SQRT(((2./(G+1.))*(MS**2))/
     -(1.-((G-1.)/(G+1.))*(MS**2)))
C
C
C     ******************************************************
C     *                                                    *
C     *          FABRI'S CRITERION APPLIES ONLY WHEN       *
C     *          (MS1.LE.1.0) AND (PS1P1.LE.1.0).          *
C     *                                                    *
C     ******************************************************
C
C
      IF(MS1.GT.(1.0)) GO TO 10
      IF((1.-MS1).LT.(1.E-4)) GO TO 100
C
C
C     ******************************************************
C     *                                                    *
C     *   CALCULATE MP2 AT STATION (2) WHERE MS2=1.0 FROM  *
C     *   THE AREA RATIO FOR STREAM (P) AT STATION (2).    *
C     *                                                    *
C     ******************************************************
C
C
      AP2PS=(AASM(GP,MP1)/AP1M3)*(1.-(1.-AP1M3)/AASM(GS,MS1))
      CALL MAAS(GP,MP1,AP2PS,SUP,5.0E-06,MP2,FAIL)
      IF(FAIL.EQ.YES) RETURN
      IF(MP2.LT.MP1) GO TO 30
      IF((MP2/MP1-1.).LT.(1.E-4)) GO TO 100
C
C
C     ******************************************************
C     *                                                    *
C     *          CALCULATE STATIC PRESSURE RATIO           *
C     *          PS1P1 BASED ON FABRI'S CRITERION.         *
C     *                                                    *
C     ******************************************************
C
C
      VD=(1.0-AP1M3)*((1.0+GS*(MS1**2))-
     -(PPOM(GS,1.0)/PPOM(GS,MS1))*((1.0+GS)/AASM(GS,MS1)))
      VN=(PPOM(GP,MP2)/PPOM(GP,MP1))*AP1M3*(AASM(GP,MP2)/
     -AASM(GP,MP1))*(1.+GP*(MP2**2))-AP1M3*(1.+GP*(MP1**2))
      PS1P1=VN/VD
      IF(PS1P1.LE.(0.0)) GO TO 50
      IF(PS1P1.GT.(1.0)) GO TO 100
      RETURN
C
```

7.5.1 CLGDSP (Cont.)

```
C                                                                        CAEFC  10100
C     ***************************************************************** CAEFC  10200
C     *                                                               * CAEFC  10300
C     *                       ERROR MESSAGES                          * CAEFC  10400
C     *                                                               * CAEFC  10500
C     ***************************************************************** CAEFC  10600
C                                                                        CAEFC  10700
C                                                                        CAEFC  10800
10    WRITE(5,20)                                                        CAEFC  10900
20    FORMAT(/,5X,'...ERROR IN CAEFC: (MS1.GT.(1.0)) .',//)              CAEFC  11000
      GO TO 90                                                           CAEFC  11100
30    WRITE(5,40)                                                        CAEFC  11200
40    FORMAT(/,5X,'...ERROR IN CAEFC: (MP2.LT.MP1).',//)                 CAEFC  11300
      GO TO 90                                                           CAEFC  11400
50    WRITE(5,60)                                                        CAEFC  11500
60    FORMAT(/,5X,'...ERROR IN CAEFC: (PS1P1.LT.(0.0)).',//)             CAEFC  11600
      GO TO 90                                                           CAEFC  11700
90    FAIL=YES                                                           CAEFC  11800
      RETURN                                                             CAEFC  11900
C                                                                        CAEFC  12000
C                                                                        CAEFC  12100
C     ***************************************************************** CAEFC  12200
C     *                                                               * CAEFC  12300
C     *                MS1 IS APPROXIMATELY 1.0 AND                   * CAEFC  12400
C     *                MP1 IS APPROXIMATELY MP1.                      * CAEFC  12500
C     *                                                               * CAEFC  12600
C     ***************************************************************** CAEFC  12700
C                                                                        CAEFC  12800
C                                                                        CAEFC  12900
100   NTYPE=3                                                            CAEFC  13000
      PS1P1=1.0                                                          CAEFC  13100
      END                                                                CAEFC  13200
```

```
C      ***************************************************************   CAEOCV 00100
C      *                                                             *   CAEOCV 00200
C      *                  CONSTANT-AREA EJECTOR                      *   CAEOCV 00300
C      *       CVERALL CCNTROL VOLUME SUBROUTINE (CAEOCV)            *   CAEOCV 00400
C      *                 (OF SUBROUTINE CAES)                        *   CAEOCV 00500
C      *                                                             *   CAEOCV 00600
C      ***************************************************************   CAEOCV 00700
C                                                                        CAEOCV 00800
C      ***************************************************************   CAEOCV 00900
C      *                                                             *   CAEOCV 01000
C      *  SUBROUTINE CAECCV PERFORMS THE CONSTANT-AREA EJECTOR.      *   CAEOCV 01100
C      *  OVERALL CCNTRCL VOLUME CALCULATIONS BY 1-D ANALYSIS        *   CAEOCV 01200
C      *  FROM INLET SECTION (1) TO MIXED SECTION (3).               *   CAEOCV 01300
C      *                                                             *   CAEOCV 01400
C      *  INPUT VARIABLES:                                           *   CAEOCV 01500
C      *                                                             *   CAEOCV 01600
C      *  GS     = SECONDARY GAMMA                                   *   CAEOCV 01700
C      *  GP     = PRIMARY GAMMA                                     *   CAEOCV 01800
C      *  MWSP   = SECCNDARY-TO-PRIMARY MOLECULAR WEIGHT RATIO       *   CAEOCV 01900
C      *  TSOPO  = SECCNDARY-TO-PRIMARY STAGNATION TEMPERATURE       *   CAEOCV 02000
C      *           RATIC                                             *   CAEOCV 02100
C      *  MS1    = SECONDARY MACH NO. AT THE MIXING TUBE             *   CAEOCV 02200
C      *           ENTRANCE                                          *   CAEOCV 02300
C      *  MP1    = PRIMARY MACH NO. AT THE MIXING TUBE ENTRANCE      *   CAEOCV 02400
C      *  AP1M3  = PRIMARY-TO-MIXING TUBE AREA RATIO                 *   CAEOCV 02500
C      *  PS1P1  = SECCNDARY-TO-PRIMARY STATIC PRESSURE RATIO        *   CAEOCV 02600
C      *                                                             *   CAEOCV 02700
C      *  OUTPUT VARIABLES:                                          *   CAEOCV 02800
C      *                                                             *   CAEOCV 02900
C      *  GM     = MIXEC STREAM GAMMA                                *   CAEOCV 03000
C      *  MWMP   = MIXEC STREAM-TO-PRIMARY MOLECULAR WEIGHT          *   CAEOCV 03100
C      *           RATIO                                             *   CAEOCV 03200
C      *  TMOPO  = MIXED STREAM-TO-PRIMARY STAGNATION                *   CAEOCV 03300
C      *           TEMPERATURE RATIO                                 *   CAEOCV 03400
C      *  MM3    = MIXED STREAM MACH NO. AT THE MIXING TUBE          *   CAEOCV 03500
C      *           EXIT                                              *   CAEOCV 03600
C      *  PPOSC  = PRIMARY-TO-SECONDARY STAGNATION PRESSURE          *   CAEOCV 03700
C      *           RATIC                                             *   CAEOCV 03800
C      *  PM3SO  = MIXED STREAM STATIC-TO-SECCNDARY STAGNATION       *   CAEOCV 03900
C      *           PRESSURE RATIO                                    *   CAEOCV 04000
C      *  FAIL   = ERROR FLAG                                        *   CAEOCV 04100
C      *                                                             *   CAEOCV 04200
C      ***************************************************************   CAEOCV 04300
C                                                                        CAEOCV 04400
C                                                                        CAEOCV 04500
       SUBROUTINE CAEOCV(GS,GP,MWSP,TSOPO,MS1,MP1,AP1M3,PS1P1,GM,        CAEOCV 04600
      -MWMP,TMOPC,MM3,PPOSO,PM3SO,FAIL)                                  CAEOCV 04700
C                                                                        CAEOCV 04800
       IMPLICIT REAL*4(M)                                                CAEOCV 04900
       DATA YES/'YES'/                                                   CAEOCV 05000
```

7.5.1 CLGDSP (Cont.)

```
C
C
C     ***********************************************************
C     *                                                         *
C     *                 GAS DYNAMIC FUNCTIONS                   *
C     *                                                         *
C     ***********************************************************
C
C
      WM(G,M)=M*SQRT(G*(1.+.5*(G-1.)*(M**2)))
      T(G,M)=(1.+G*(M**2))/(M*SQRT(1.+.5*(G-1.)*(M**2)))
      PPOM(G,M)=(1.+.5*(G-1.)*(M**2))**(-G/(G-1.))
C
C
C     ***********************************************************
C     *                                                         *
C     *                EJECTOR MASS FLOW RATIO                  *
C     *                                                         *
C     ***********************************************************
C
C
      C0=SQRT(MWSP/TSOPO)
      WSP=PS1P1*((1.-AP1M3)/AP1M3)*C0*(WM(GS,MS1)/WM(GP,MP1))
      CPSP=(GS/GP)*((GP-1.)/(GS-1.))/MWSP
C
C
C     ***********************************************************
C     *                                                         *
C     *                 MIXED FLOW PROPERTIES                   *
C     *                                                         *
C     ***********************************************************
C
C
      MWMP=(1.+WSP)/(1.+(WSP/MWSP))
      GM=1./(1.-((GP-1.)/GP)*((1.+(WSP/MWSP))/(1.+CPSP*WSP)))
      TMOPO=(1.+WSP*CPSP*TSOPO)/(1.+WSP*CPSP)
C
C
C     ***********************************************************
C     *                                                         *
C     *                     SOLVE FOR MM3                       *
C     *                                                         *
C     ***********************************************************
C
C
      C1=SQRT((TSOPO/MWSP)*(GP/GS))
      C2=SQRT(TMOPO/MWMP*(GP/GM))
      TM3=(T(GP,MP1)+C1*WSP*T(GS,MS1))/((1.+WSP)*C2)
      TM3MIN=SQRT(2.*(GM+1.))
      IF(TM3.LT.TM3MIN) GO TO 10
```

7.5.1 CLGDSP (Cont.)

```
      C3=(TM3**2-2.*GM)                                                 CAEOCV 10100
      C4=(((GM-1.)/2.)*(TM3**2)-GM**2)                                  CAEOCV 10200
      C5=SQRT(C3**2+4.*C4)                                              CAEOCV 10300
      MSQD3M=(-C3-C5)/(2.*C4)                                           CAEOCV 10400
      MSQD3P=(-C3+C5)/(2.*C4)                                           CAEOCV 10500
C                                                                       CAEOCV 10600
C                                                                       CAEOCV 10700
C     ***************************************************************** CAEOCV 10800
C     *                                                               * CAEOCV 10900
C     *        DETERMINE TWO POSSIBLE MIXED-FLOW MACH NO.             * CAEOCV 11000
C     *        SOLUTICNS.  USE CNLY SUBSONIC RESULT AT (3).           * CAEOCV 11100
C     *                                                               * CAEOCV 11200
C     ***************************************************************** CAEOCV 11300
C                                                                       CAEOCV 11400
C                                                                       CAEOCV 11500
      IF(MSQD3M.GE.(0.0)) MM3M=SQRT(MSQD3M)                             CAEOCV 11600
      IF(MSQD3P.GE.(0.0)) MM3P=SQRT(MSQD3P)                             CAEOCV 11700
      MM3=MM3P                                                          CAEOCV 11800
C                                                                       CAEOCV 11900
C                                                                       CAEOCV 12000
C     ***************************************************************** CAEOCV 12100
C     *                                                               * CAEOCV 12200
C     *                  CALCULATE PRESSURE RATIOS                    * CAEOCV 12300
C     *                                                               * CAEOCV 12400
C     ***************************************************************** CAEOCV 12500
C                                                                       CAEOCV 12600
C                                                                       CAEOCV 12700
      C6=SQRT(TMOPO/MWMP)                                               CAEOCV 12800
      PM3P1=C6*AP1M3*(1.+WSP)*(WM(GP,MP1)/WM(GM,MM3))                   CAEOCV 12900
      PPOSO=(PPOM(GS,MS1)/PPOM(GP,MP1))/PS1P1                           CAEOCV 13000
      PM3SO=PM3P1*(PPOM(GS,MS1)/PS1P1)                                  CAEOCV 13100
      PMOSC=PM3SO/PPOM(GM,MM3)                                          CAEOCV 13200
      RETURN                                                            CAEOCV 13300
C                                                                       CAEOCV 13400
C                                                                       CAEOCV 13500
C     ***************************************************************** CAEOCV 13600
C     *                                                               * CAEOCV 13700
C     *                        ERROR MESSAGES                         * CAEOCV 13800
C     *                                                               * CAEOCV 13900
C     ***************************************************************** CAEOCV 14000
C                                                                       CAEOCV 14100
C                                                                       CAEOCV 14200
1C    WRITE(6,2C)                                                       CAEOCV 14300
2C    FORMAT(/,5X,'...ERROR IN CAEOCV: NO SOLUTICN.',/)                 CAEOCV 14400
      FAIL=YES                                                          CAEOCV 14500
      END                                                               CAEOCV 14600
```

7.5.1 CLGDSP (Cont.)

```
C     ***********************************************************
C     *                                                         *
C     *     SUPERSONIC-SUPERSONIC EJECTOR SUBROUTINE (SSES)     *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *  SUBROUTINE SSES CALCULATES THE MAXIMUM COMPRESSION     *
C     *  RATIC FCR A CONSTANT-AREA, SUPERSONIC-SUPERSONIC       *
C     *  EJECTOR, BY ONE-DIMENSIONAL ANALYSIS, ASSUMING AN      *
C     *  ISENTROPIC RECOMPRESSION OF THE SECCNDARY STREAM TO    *
C     *  SCNIC CONDITIONS.                                      *
C     *                                                         *
C     *  INPUT VARIABLES:                                       *
C     *                                                         *
C     *  GS     = SECCNDARY GAMMA                               *
C     *  GP     = PRIMARY GAMMA                                 *
C     *  MWSMWP = SECCNDARY-TO-PRIMARY MOLECULAR WEIGHT RATIO   *
C     *  TSOTPO = SECCNDARY-TO-PRIMARY STAGNATION TEMPERATURE   *
C     *           RATIC                                         *
C     *  MS1    = SECONDARY MACH NO. AT THE MIXING TUBE         *
C     *           ENTRANCE                                      *
C     *  MP1    = PRIMARY MACH NO. AT THE MIXING TUBE ENTRANCE  *
C     *  AS1AP1 = SECCNDARY-TO-PRIMARY AREA RATIO               *
C     *                                                         *
C     *  OUTPUT VARIABLES:                                      *
C     *                                                         *
C     *  WSWP   = SECCNDARY-TO-PRIMARY MASS FLOW RATIO          *
C     *  GM     = MIXED STREAM GAMMA                            *
C     *  MWMMWP = MIXED STREAM-TO-PRIMARY MOLECULAR WEIGHT      *
C     *           RATIC                                         *
C     *  TMOTPC = MIXED STREAM-TO-PRIMARY STAGNATION            *
C     *           TEMPERATURE RATIO                             *
C     *  MM3    = MIXED STREAM MACH NO. AT THE MIXING TUBE      *
C     *           EXIT                                          *
C     *  PPOPS1 = PRIMARY STAGNATION-TO-SECCNDARY STATIC        *
C     *           PRESSURE RATIO                                *
C     *  PM3PS1 = STATIC PRESSURE COMPRESSION RATIO             *
C     *  FAIL   = ERROR FLAG                                    *
C     *                                                         *
C     ***********************************************************
C
C
      SUBROUTINE SSES(GS,GP,MWSMWP,TSOTPO,MS1,MP1,AS1AP1,WSWP,
     -GM,MWMMWP,TMOTPO,MM3,PPOPS1,PM3PS1,FAIL)
C
      IMPLICIT REAL*4(M)
      DATA YES/'YES'/,SUP/'SUP'/
C
```

7.5.1 CLGDSP (Cont.)

```
C
C     ************************************************************
C     *                                                          *
C     *                   SPECIAL FUNCTIONS                      *
C     *                                                          *
C     ************************************************************
C
C
      F(GX,MXX)=1.0+GX*MXX*MXX
      G(GX,MXX)=MXX*SQRT(1.0+0.5*(GX-1.0)*MXX*MXX)
      H(MM,TT,GG)=SQRT(MM*GG/TT)
      PPO(GX,MXX)=(1.0+0.5*(GX-1.0)*MXX*MXX)**(GX/(1.0-GX))
      AAS(GX,MXX)=((2.0*(1.0+0.5*(GX-1.0)*MXX*MXX)/(GX+1.0))**(0.5*(GX+1
     -.0)/(GX-1.0)))/MXX
C
C
C     ************************************************************
C     *                                                          *
C     *                  CALCULATE CONSTANTS                     *
C     *                                                          *
C     ************************************************************
C
C
      GS3=GS/(GS-1.0)
      GP3=GP/(GP-1.0)
      GSGP=GS/GP
      MWPMWS=1.0/MWSMWP
      PP1PPO=PPO(GP,MP1)
      AS1ASS=AAS(GS,MS1)
      AP1APS=AAS(GP,MP1)
      ASSAS1=1.0/AS1ASS
      FGSMS1=F(GS,MS1)
      FGPMP1=F(GP,MP1)
      GGSMS1=G(GS,MS1)
      GGPMP1=G(GP,MP1)
C
C
C     ************************************************************
C     *                                                          *
C     *  CALCULATE FS1PP1 FOR AN ISENTROPIC RECOMPRESSION TO     *
C     *  SONIC CONDITIONS.  MP2 IS OBTAINED FROM AP2APS.         *
C     *                                                          *
C     ************************************************************
C
C
      IF(AS1AP1.GE.0.0) GO TO 1
      WRITE(5,2)AS1AP1
      FAIL=YES
      RETURN
    1 AP2APS=AP1APS*(1.0+AS1AP1*(1.0-ASSAS1))
```

7.5.1 CLGDSP (Cont.)

```
      CALL MAAS(GP,MP1,AP2APS,SUP,5.0E-06,MP2,FAIL)
      IF(FAIL.EQ.YES) RETURN
      MS2=1.0
      C1=-FGPMP1+F(GP,MP2)*GGPMP1/G(GP,MP2)
      C2=FGSMS1-F(GS,MS2)*GGSMS1/G(GS,MS2)
      PS1PP1=C1/(AS1AP1*C2)
C
C
C     ***********************************************************
C     *                                                         *
C     *            OVERALL CONTROL VOLUME CALCULATIONS          *
C     *                                                         *
C     ***********************************************************
C
C
      WSWP=PS1PP1*AS1AP1*H(MWSMWP,TSOTPO,GSGP)*GGSMS1/GGPMP1
      C1=WSWP*MWFMWS*GS3+GP3
      C2=WSWP*MWFMWS*(GS3-1.0)+(GP3-1.0)
      GM=C1/C2
      GMGP=GM/GP
      MWMMWP=(WSWP+1.0)/(WSWP*MWPMWS+1.0)
      C1=TSOTPO*WSWP*MWPMWS*GS3+GP3
      C2=WSWP*MWFMWS*GS3+GP3
      TMOTPO=C1/C2
      FFX=H(MWMMWP,TMOTPO,GMGP)*(PS1PP1*AS1AP1*FGSMS1+FGPMP1)/(
     -(1.0+WSWP)*GGPMP1)
      C1=0.5*(GM-1.0)*FFX*FFX-GM*GM
      C2=FFX*FFX-2.0*GM
      C3=(-C2+SQRT(C2*C2+4.0*C1))/(2.0*C1)
      C4=(-C2-SQRT(C2*C2+4.0*C1))/(2.0*C1)
      MM3=SQRT(AMIN1(C3,C4))
      PM3PP1=(PS1PP1*AS1AP1*FGSMS1+FGPMP1)/((1.0+AS1AP1)*F(GM,MM3))
      PM3PS1=PM3PP1/PS1PP1
      PS1PP0=PS1PP1*PP1PP0
      PP0PS1=1.0/PS1PP0
C
C
C     ***********************************************************
C     *                                                         *
C     *                   FORMAT STATEMENTS                     *
C     *                                                         *
C     ***********************************************************
C
C
    2 FORMAT('0',T2,'IMPOSSIBLE VALUE...AS1AP1 =',E13.6)
      END
```

7.5.1 CLGDSP (Cont.)

```
C       **************************************************************
C       *                                                            *
C       *                   SUBROUTINE (MAAS)                        *
C       *                                                            *
C       **************************************************************
C
C       **************************************************************
C       *                                                            *
C       *  SUBROUTINE MAAS CALCULATES THE MACH NUMBER (M) GIVEN      *
C       *  THE AREA RATIO (A/A*) BY LINEAR ITERATION.                *
C       *                                                            *
C       *  INPUT VARIABLES:                                          *
C       *                                                            *
C       *  G      = SPECIFIC HEAT RATIO                              *
C       *  MINI   = INITIAL VALUE OF MACH NUMBER                     *
C       *  AAS    = THE AREA RATIO A/A*                              *
C       *  FLOW   = CONTROL VARIABLE SUCH THAT                       *
C       *         = "SUB" FOR THE SUBSONIC BRANCH                    *
C       *         = "SUP" FOR THE SUPERSONIC BRANCH                  *
C       *  ERROR  = MAX PERCENT DEVIATION IN MOLD AND MNEW FOR       *
C       *           A SOLUTION                                       *
C       *                                                            *
C       *  OUTPUT VARIABLES:                                         *
C       *                                                            *
C       *  MNEW   = FINAL VALUE OF MACH NUMBER                       *
C       *  FAIL   = ERROR FLAG                                       *
C       *                                                            *
C       **************************************************************
C
C
        SUBROUTINE MAAS(G,MINI,AAS,FLOW,ERROR,MNEW,FAIL)
C
        IMPLICIT REAL*4(M)
        DATA YES/'YES'/,SUP/'SUP'/
C
C
C       **************************************************************
C       *                                                            *
C       *                   CALCULATE CONSTANTS                      *
C       *                                                            *
C       **************************************************************
C
C
        G1=(G-1.0)/2.0
        G1I=1.0/G1
        G2=2.0/(G+1.0)
        G2I=1.0/G2
        G4=(G+1.0)/(2.0*(G-1.0))
        G4I=1.0/G4
C
```

7.5.1 CLGDSP (Cont.)

```
C                                                                       MAAS 05100
C     ***************************************************************  MAAS 05200
C     *                                                             *  MAAS 05300
C     *              CALCULATE THE SUPERSONIC BRANCH                *  MAAS 05400
C     *                                                             *  MAAS 05500
C     ***************************************************************  MAAS 05600
C                                                                       MAAS 05700
C                                                                       MAAS 05800
      MOLD=MINI                                                         MAAS 05900
      IF(FLOW.NE.SUP) GO TO 2                                           MAAS 06000
      DO 1 J=1,200                                                      MAAS 06100
      C1=(MOLD*AAS)**G4I                                                MAAS 06200
      MNEW=SQRT(G1I*(G2I*C1-1.0))                                       MAAS 06300
      XERROR=(MNEW-MOLD)*100.0/MOLD                                     MAAS 06400
      MOLD=MNEW                                                         MAAS 06500
      IF(ABS(XERROR).LT.ERROR) RETURN                                   MAAS 06600
1     CONTINUE                                                          MAAS 06700
      GO TO 4                                                           MAAS 06800
C                                                                       MAAS 06900
C                                                                       MAAS 07000
C     ***************************************************************  MAAS 07100
C     *                                                             *  MAAS 07200
C     *              CALCULATE THE SUBSONIC BRANCH                  *  MAAS 07300
C     *                                                             *  MAAS 07400
C     ***************************************************************  MAAS 07500
C                                                                       MAAS 07600
C                                                                       MAAS 07700
2     DO 3 J=1,200                                                      MAAS 07800
      C1=1.0+G1*MOLD*MOLD                                               MAAS 07900
      MNEW=((G2*C1)**G4)/AAS                                            MAAS 08000
      XERROR=(MNEW-MOLD)*100.0/MOLD                                     MAAS 08100
      MOLD=MNEW                                                         MAAS 08200
      IF(ABS(XERROR).LT.ERROR) RETURN                                   MAAS 08300
3     CONTINUE                                                          MAAS 08400
C                                                                       MAAS 08500
C                                                                       MAAS 08600
C     ***************************************************************  MAAS 08700
C     *                                                             *  MAAS 08800
C     *                   CONVERGENCE FAILURE                       *  MAAS 08900
C     *                                                             *  MAAS 09000
C     ***************************************************************  MAAS 09100
C                                                                       MAAS 09200
C                                                                       MAAS 09300
4     WRITE(5,5)FLOW,G,MINI,MNEW,AAS XERROR,ERROR                       MAAS 09400
      FAIL=YES                                                          MAAS 09500
5     FORMAT('0',T2,'CONVERGENCE FAILURE FOR ',A3,'SONIC ',             MAAS 09600
     -'BRANCH IN SUBROUTINE MAAS',/,                                    MAAS 09700
     -T2,'G      =',E13.6,2X,'MINI    =',E13.6,/,                       MAAS 09800
     -T2,'MNEW   =',E13.6,2X,'AAS     =',E13.6,/,                       MAAS 09900
     -T2,'XERROR =',E13.6,2X,'ERROR   =',E13.6)                         MAAS 10000
```

7.5.1 CLGDSP (Cont.)

```
MAAS      10100

END
```

```
C     ***********************************************************
C     *                                                         *
C     *             ITERATION SUBROUTINE (ITER)                 *
C     *                                                         *
C     ***********************************************************
C
C     ***********************************************************
C     *                                                         *
C     *  SUBROUTINE ITER PERFORMS AN ITERATION TO FIND X SUCH   *
C     *  THAT THE PERCENT ERROR IN Y AND YGIVEN IS .LE. TO      *
C     *  ERRORY OR THE PERCENT DEVIATION IN X(I+1) AND X(I)     *
C     *  IS .LE. TO ERRORX.                                     *
C     *                                                         *
C     * VARIABLES:                                              *
C     *                                                         *
C     * X      = INDEPENDENT VARIABLE                           *
C     * DX     = INCREMENT IN INDEPENDENT VARIABLE              *
C     * ERRORX = MAX PERCENT DEVIATION IF X(I+1) AND X(I) FOR   *
C     *          SOLUTION                                       *
C     * SIGN   = +1.0 OR -1.0, +/- INCREMENTING FROM INITIAL X  *
C     * Y      = DEPENDENT VARIABLE                             *
C     * YGIVEN = GIVEN VALUE OF DEPENDENT VARIABLE              *
C     * ERRORY = MAX PERCENT ERROR IN Y AND YGIVEN FOR          *
C     *          SOLUTION                                       *
C     * NIT    = INCREMENT NUMBER                               *
C     * NTYPE  = 1--INCREMENT,  2--INTERPOLATION,  3--SOLUTION  *
C     *                                                         *
C     * NOTE: THE INTERMEDIATE VARIABLES XNEG,YNEG,XPOS,YPOS,   *
C     * NSIGN1,NSIGN2 MUST BE STORED BETWEEN INTERATIONS.       *
C     *                                                         *
C     ***********************************************************
C
      SUBROUTINE ITER(X,DX,ERRORX,SIGN,Y,YGIVEN,ERRORY,NIT,
     -NTYPE,XNEG,YNEG,XPOS,YPOS,NSIGN1,NSIGN2)
C
      ERROR(ACTUAL,GIVEN)=(ACTUAL-GIVEN)*100.0/GIVEN
C
      IF(ABS(ERROR(Y,YGIVEN))-ERRORY) 90,90,10
   10 IF(Y-YGIVEN) 20,90,30
   20 NSIGN2=-1
      XNEG=X
      YNEG=Y
      GO TO 40
   30 NSIGN2=+1
      XPOS=X
      YPOS=Y
   40 GO TO (50,80), NTYPE
   50 IF(NIT-1) 70,70,60
   60 NSIGN=NSIGN1*NSIGN2
```

```
      IF(NSIGN) 80,80,70                                                ITER  05100
   70 NSIGN1=NSIGN2                                                     ITER  05200
      NIT=NIT+1                                                         ITER  05300
C                                                                       ITER  05400
C                                                                       ITER  05500
C     ***************************************************************** ITER  05600
C     *                                                               * ITER  05700
C     *             INCREMENT TO FIND SOLUTION INTERVAL               * ITER  05800
C     *                                                               * ITER  05900
C     ***************************************************************** ITER  06000
C                                                                       ITER  06100
C                                                                       ITER  06200
      X=X+SIGN*DX                                                       ITER  06300
      GO TO 100                                                         ITER  06400
C                                                                       ITER  06500
C                                                                       ITER  06600
C     ***************************************************************** ITER  06700
C     *                                                               * ITER  06800
C     *                  INTERPOLATION FOR SOLUTION                   * ITER  06900
C     *                                                               * ITER  07000
C     ***************************************************************** ITER  07100
C                                                                       ITER  07200
C                                                                       ITER  07300
   80 NTYPE=2                                                           ITER  07400
      NIT=NIT+1                                                         ITER  07500
      XSAVE=X                                                           ITER  07600
      RATIO=(XPOS-XNEG)/(YPOS-YNEG)                                     ITER  07700
      X=XNEG+RATIO*(YGIVEN-YNEG)                                        ITER  07800
C                                                                       ITER  07900
C                                                                       ITER  08000
C     ***************************************************************** ITER  08100
C     *                                                               * ITER  08200
C     *          ACCELERATION OF CONVERGENCE OF ITERATION             * ITER  08300
C     *                 REFERENCE - WEGSTEIN, NBS                     * ITER  08400
C     *                                                               * ITER  08500
C     ***************************************************************** ITER  08600
C                                                                       ITER  08700
C                                                                       ITER  08800
      A=1.0/RATIO                                                       ITER  08900
      IF(A-1.0) 82,88,82                                                ITER  09000
   82 Q=A/(A-1.0)                                                       ITER  09100
      XWGSTN=Q*XSAVE+(1.0-Q)*X                                          ITER  09200
      IF(XNEG-XWGSTN) 84,86,88                                          ITER  09300
   84 IF(XWGSTN-XPOS) 86,86,88                                          ITER  09400
   86 X=XWGSTN                                                          ITER  09500
   88 IF(ABS(ERROR(X,XSAVE))-ERRORX) 90,90,100                          ITER  09600
   90 NTYPE=3                                                           ITER  09700
  100 END                                                               ITER  09800
```

7.5.1 CLGDSP (Cont.)

```
C     **************************************************************
C     *                                                            *
C     *                    SUBROUTINE (TTY)                        *
C     *                                                            *
C     **************************************************************
C
C     **************************************************************
C     *                                                            *
C     *  SUBRCUTINE TTY PRINTS THE RESULTS OF PROGRAM CLGDSP       *
C     *  ON TERMINALS WITH A MINIMUM OF 72 CHARACTERS PER          *
C     *  LINE.  SEE MAIN PROGRAM CLGDSP FOR NOTATION.              *
C     *                                                            *
C     **************************************************************
C
      SUBRCUTINE TTY
C
      IMPLICIT REAL*4(M)
      DATA CPE/'CPE'/,CAE/'CAE'/,SSE/'SSE'/
C
      COMMCN/TTY1/A2A1,A3A1,A4A1,A4A3,A5A1,A5A6,A6A1,A7A1,A7A2,
     -A7A6,A8A1,A8A7
      COMMON/TTY2/COEFF,CQ1,CQ2,EJECT,GM,GP,GS
      COMMCN/TTY3/M1,M2,M3,M4,M5,M6,M7,M8,MWMMWS,MWPMWS,NPTS
      COMMCN/TTY4/P1P10,P2P1,P20P10,P3P1,P30P10,P3P2,P30P20,
     -P4P1,P40P10,P4P3,P40P30,P5P1,P50P10,P6OP1,P60P10,P60P2,
     -P60P20,P60P50,P7P1,P70P10,P7P2,P70P20,P7P50,P70P50,XP8P1,
     -P80P10,P8P2,P80P20,P8P7,P80P70
      COMMCN/TTY5/RCPE,RNSD,RSD34,RSD78
      COMMCN/TTY6/T1T10,T2T1,T20T10,T3T1,T30T10,T3T2,T30T20,
     -T4T1,T40T10,T4T3,T40T30,T5T1,T50T10,T60T1,T60T10,T60T20,
     -T60T50,T7T1,T7CT10,T7T2,T70T20,T7T50,T70T50,T8T1,
     -T80T10,T8T2,T80T2C,T8T7,T80T70
      COMMCN/TTY7/WMWS,WPWS
C
C     **************************************************************
C     *                                                            *
C     *                   OUTPUT SYSTEM DATA                       *
C     *                                                            *
C     **************************************************************
C
      WRITE(5,2CC)
      WRITE(5,2C1)EJECT,COEFF
C
      WRITE(5,2C2)
      WRITE(5,2C3)
      WRITE(5,204)M1,GS,P1P1C,T1T10
C
```

```
      WRITE(5,205)
      IF(EJECT.NE.SSE) WRITE(5,206)
      IF(EJECT.EQ.SSE) WRITE(5,207)
      WRITE(5,208)GS,M2,A2A1,P2P1,T2T1,P20P10,T20T10
C
      IF(EJECT.EQ.SSE) GO TO 100
      WRITE(5,209)
      WRITE(5,210)GS,M3,A3A1,P3P1,T3T1,P30P10,T30T10
C
      WRITE(5,211)
      WRIT (5,212)GS,M4,A4A1,P4P1,T4T1,P40P1C,T40T10
C
      IF(EJECT.EQ.CPE) WRITE(5,213)
      IF(EJECT.EQ.CAE) WRITE(5,214)
      WRITE(5,215)GS,M5,A5A1,P5P1,T5T1,P50P10,,50T10
C
      IF(EJECT.EQ.CPE) WRITE(5,216)
      IF(EJECT.EQ.CAE) WRITE(5,217)
      GO TO 101
100   WRITE(5,218)
101   WRITE(5,219)GF,MWPMWS,WPWS,M6,A6A1,P60F1,T60T1,P60P10,
     -T60T10
C
      IF(EJECT.EQ.CPE) WRITE(5,220)
      IF(EJECT.EC.CAE) WRITE(5,221)
      IF(EJECT.EQ.SSE) WRITE(5,222)
      WRITE(5,223)GW,MWMMWS,WMWS,M7,A7A1,P7P1,T7T1,P70P10,T70T10
C
      WRITE(5,224)
      WRITE(5,225)GW,MWMMWS,WMWS,M8,A8A1,XP8P1,T8T1,P80P10,
     -T80T10
C
C
C     ***********************************************************
C     *                                                         *
C     *                 OUTPUT DATA FOR EACH DEVICE             *
C     *                                                         *
C     ***********************************************************
C
C
      WRITE(5,300)
      WRITE(5,301)NFTS,CQ1,CQ2,GS,A2A1,M1,M2,P2P1,T2T1,P20P10,
     -T20T10
C
      IF(EJECT.EQ.SSE) GO TO 102
      WRITE(5,302)
      WRITE(5,303)GS,RNSD,M2,M3,P3P2,T3T2,P30P20,T30T20
C
      WRITE(5,304)
      WRITE(5,305)RSC34,GS,A4A3,M3,M4,P4P3,T4T3,P40P30,T40T30
```

```
C
      IF(EJECT.EQ.CPE) WRITE(5,306)
      IF(EJECT.EQ.CAE) WRITE(5,307)
      WRITE(5,308)GS,GP,GM,MWPMWS,A7A6,WPWS,M6,M7,P60P50,T60T50,
     -P7P50,T7T50,P70P50,T70T50
      IF(EJECT.EQ.CPE) WRITE(5,309)RCPE,A5A6
C
      WRITE(5,310)
      IF(EJECT.EQ.CPE) WRITE(5,311)
      IF(EJECT.EQ.CAE) WRITE(5,312)
      GO TO 103
102   WRITE(5,313)
103   WRITE(5,314)GS,GP,GM,MWPMWS,A7A2,A7A6,WPWS,M2,M6,M7,P60P2,
     -P60P20,T60T20,P7P2,T7T2,P70P20,T70T20
C
      IF(EJECT.NE.SSE) WRITE(5,315)
      IF(EJECT.EQ.CPE) WRITE(5,316)
      IF(EJECT.EQ.CAE) WRITE(5,317)
      IF(EJECT.EQ.SSE) WRITE(5,318)
      WRITE(5,319)GS,GP,GM,MWPMWS,A7A2,A7A6,A8A7,WPWS,M2,M6,M7,
     -M8,P60P2,P60P20,T60T20,P8P2,T8T2,P80P20,T80T20
C
      WRITE(5,320)
      WRITE(5,321)RSC78,GM,A8A7,M7,M8,P8P7,T8T7,P80P70,T80T70
C
C
C     **************************************************************
C     *                                                            *
C     *                    FORMAT STATEMENTS                       *
C     *                                                            *
C     **************************************************************
C
C
200   FORMAT('1',T14,'HIGH ENERGY CHEMICAL LASER SYSTEM ',
     -'SIMULATION',/,T24,'ONE-DIMENSIONAL ANALYSIS',//,T29,
     -'A.L. ADDY',/,T29,'C.C. MIKKELSEN',/,T29,'M.R. SANDBERG',
     -//,T30,'1 JANUARY 76',//,T19,'MECHANICAL ENGINEERING ',
     -'DEPARTMENT',/,T15,'UNIVERSITY OF ILLINOIS AT URBANA-',
     -'CHAMPAIGN',/,T25,'URBANA, ILLINOIS 61801')
201   FORMAT('0',T18,A3,' SOLUTION WITH ITERATION ON ',A4)
C
202   FORMAT('0',T14,'SYSTEM DATA:')
203   FORMAT('0',T5,'POINT 1  LASER CAVITY ENTRANCE CONDITIONS')
204   FORMAT('0',T14,'M1      =',E13.6,T38,'GS      =',E13.6,/,
     -T14,'P1P10   =',E13.6,T38,'T1T10   =',E13.6)
C
205   FORMAT('0',T5,'POINT 2  LASER CAVITY EXIT AND')
206   FORMAT('+',T36,'NORMAL SHOCK DIFFUSER',/,T14,'ENTRANCE ',
     -'CONDITIONS')
207   FORMAT('+',T36,'SUPERSONIC-SUPERSONIC',/,T14,'EJECTOR ',
```

7.5.1 CLGDSP (Cont.)

```
      -'ENTRANCE CONDITICNS')                                   TTY
208    FORMAT('0',T14,'GS       =',E13.6,/,                     TTY
      -T14,'M2       =',E13.6,T38,'A2A1    =',E13.6,/,          TTY
      -T14,'P2P1     =',E13.6,T38,'T2T1    =',E13.6,/,          TTY
      -T14,'P20P10 =',E13.6,T38,'T20T10 =',E13.6)               TTY
C                                                               TTY
209    FORMAT('0',T5,'POINT 3  NORMAL SHOCK DIFFUSER EXIT AND ',   TTY
      -'SUBSONIC',/,T14,'DIFFUSER ENTRANCE CONDITIONS')         TTY
210    FORMAT('0',T14,'GS       =',E13.6,/,                     TTY
      -T14,'M3       =',E13.6,T38,'A3A1    =',E13.6,/,          TTY
      -T14,'P3P1     =',E13.6,T38,'T3T1    =',E13.6,/,          TTY
      -T14,'P30P10 =',E13.6,T38,'T30T10 =',E13.6)               TTY
C                                                               TTY
211    FORMAT('0',T5,'POINT 4  SUBSONIC DIFFUSER EXIT AND ',    TTY
      -'SUDDEN ENLARGEMENT',/,T14,'ENTRANCE CONDITIONS')        TTY
212    FORMAT('0',T14,'GS       =',E13.6,/,                     TTY
      -T14,'M4       =',E13.6,T38,'A4A1    =',E13.6,/,          TTY
      -T14,'P4P1     =',E13.6,T38,'T4T1    =',E13.6,/,          TTY
      -T14,'P40P10 =',E13.6,T38,'T40T10 =',E13.6)               TTY
C                                                               TTY
213    FORMAT('0',T5,'POINT 5  CONSTANT-PRESSURE EJECTOR ',     TTY
      -'SECONDARY NOZZLE',/,T14,'EXIT CONDITIONS')              TTY
214    FORMAT('0',T5,'POINT 5  CONSTANT-AREA EJECTOR SECONDARY ',  TTY
      -'NOZZLE EXIT',/,T14,'CONDITIONS')                        TTY
215    FORMAT('0',T14,'GS       =',E13.6,/,                     TTY
      -T14,'M5       =',E13.6,T38,'A5A1    =',E13.6,/,          TTY
      -T14,'P5P1     =',E13.6,T38,'T5T1    =',E13.6,/,          TTY
      -T14,'P50P10 =',E13.6,T38,'T50T10 =',E13.6)               TTY
C                                                               TTY
216    FORMAT('0',T5,'POINT 6  CONSTANT-PRESSURE EJECTOR ',     TTY
      -'PRIMARY NOZZLE EXIT',/,T14,'CONDITIONS')                TTY
217    FORMAT('0',T5,'POINT 6  CONSTANT-AREA EJECTOR PRIMARY ',  TTY
      -'NOZZLE EXIT',/,T14,'CONDITIONS')                        TTY
218    FORMAT('0',T5,'POINT 6  SUPERSONIC-SUPERSONIC EJECTOR ',  TTY
      -'PRIMARY NOZZLE',/,T14,'EXIT CONDITIONS')                TTY
219    FORMAT('0',T14,'GP       =',E13.6,T38,'MWPMWS =',E13.6,/,  TTY
      -T14,'WPWS     =',E13.6,/,                                TTY
      -T14,'M6       =',E13.6,T38,'A6A1    =',E13.6,/,          TTY
      -T14,'P60P1    =',E13.6,T38,'T60T1   =',E13.6,/,          TTY
      -T14,'P60P10 =',E13.6,T38,'T60T10 =',E13.6)               TTY
C                                                               TTY
220    FORMAT('0',T5,'POINT 7  CONSTANT-PRESSURE EJECTOR EXIT ',  TTY
      -'AND SUBSONIC',/,T14,'DIFFUSER ENTRANCE CONDITIONS')     TTY
221    FORMAT('0',T5,'POINT 7  CONSTANT-AREA EJECTOR EXIT AND ',  TTY
      -'SUBSONIC',/,T14,'DIFFUSER ENTRANCE CONDITIONS')         TTY
222    FORMAT('0',T5,'POINT 7  SUPERSONIC-SUPERSONIC EJECTOR ',  TTY
      -'EXIT AND',/,T14,'SUBSONIC DIFFUSER ENTRANCE CONDITIONS')  TTY
223    FORMAT('0',T14,'GM       =',E13.6,T38,'MWMMWS =',E13.6,/,  TTY
      -T14,'WMWS     =',E13.6,/,                                TTY
      -T14,'M7       =',E13.6,T38,'A7A1    =',E13.6,/,          TTY
```

```
     -T14,'P7P1    =',E13.6,T38,'T7T1    =',E13.6,/,
     -T14,'P70P10 =',E13.6,T38,'T70T10 =',E13.6)
C
224   FORMAT('0',T5,'POINT 8  SUBSONIC DIFFUSER EXIT ',
     -'CONDITIONS')
225   FORMAT('0',T14,'GM      =',E13.6,T38,'MWMMWS =',E13.6,/,
     -T14,'WMWS    =',E13.6,/,
     -T14,'M8      =',E13.6,T38,'A8A1    =',E13.6,/,
     -T14,'P8P1    =',E13.6,T38,'T8T1    =',E13.6,/,
     -T14,'P80P10 =',E13.6,T38,'T80T10 =',E13.6)
C
300   FORMAT('0',T14,'LASER CAVITY DATA:')
301   FORMAT('0',T14,'NPTS    =',I13,/,
     -T14,'CQ1     =',E13.6,T38,'CQ2     =',E13.6,/,
     -T14,'GS      =',E13.6,T38,'A2A1    =',E13.6,/,
     -T14,'M1      =',E13.6,T38,'M2      =',E13.6,/,
     -T14,'P2P1    =',E13.6,T38,'T2T1    =',E13.6,/,
     -T14,'P20P10 =',E13.6,T38,'T20T10 =',E13.6)
C
302   FORMAT('0',T14,'NORMAL SHOCK DIFFUSER DATA:')
303   FORMAT('0',T14,'GS      =',E13.6,T38,'RNSD    =',E13.6,/,
     -T14,'M2      =',E13.6,T38,'M3      =',E13.6,/,
     -T14,'P3P2    =',E13.6,T38,'T3T2    =',E13.6,/,
     -T14,'P30P20 =',E13.6,T38,'T30T20 =',E13.6)
C
304   FORMAT('0',T14,'SUBSONIC DIFFUSER DATA:')
305   FORMAT('0',T14,'RSD     =',E13.6,/,
     -T14,'GS      =',E13.6,T38,'A4A3    =',E13.6,/,
     -T14,'M3      =',E13.6,T38,'M4      =',E13.6,/,
     -T14,'P4P3    =',E13.6,T38,'T4T3    =',E13.6,/,
     -T14,'P40P30 =',E13.6,T38,'T40T30 =',E13.6)
C
306   FORMAT('0',T14,'CONSTANT-PRESSURE EJECTOR DATA:')
307   FORMAT('0',T14,'CONSTANT-AREA EJECTOR DATA:')
308   FORMAT('0',T14,'GS      =',E13.6,T38,'GP      =',E13.6,/,
     -T14,'GM      =',E13.6,T38,'MWPMWS =',E13.6,/,
     -T14,'A7A6    =',E13.6,T38,'WPWS    =',E13.6,/,
     -T14,'M6      =',E13.6,T38,'M7      =',E13.6,/,
     -T14,'P60P50 =',E13.6,T38,'T60T50 =',E13.6,/,
     -T14,'P7P5C   =',E13.6,T38,'T7T50   =',E13.6,/,
     -T14,'P70P50 =',E13.6,T38,'T70T50 =',E13.6)
309   FORMAT(' ',T14,'RCPE    =',E13.6,T38,'A5A6    =',E13.6)
C
310   FORMAT('0',T14,'NORMAL SHOCK DIFFUSER - SUBSONIC ',
     -'DIFFUSER -')
311   FORMAT(' ',T14,'CONSTANT-PRESSURE EJECTOR DATA:')
312   FORMAT(' ',T14,'CONSTANT-AREA EJECTOR DATA:')
313   FORMAT('0',T14,'SUPERSONIC-SUPERSONIC EJECTOR DATA:')
314   FORMAT('0',T14,'GS      =',E13.6,T38,'GP      =',E13.6,/,
     -T14,'GM      =',E13.6,T38,'MWPMWS =',E13.6,/,
```

```
      -T14,'A7A2    =',E13.6,T38,'A7A6    =',E13.6,/,                    TTY    25100
      -T14,'WPWS    =',E13.6,T38,'M2      =',E13.6,/.                    TTY    25200
      -T14,'M6      =',E13.6,T38,'M7      =',E13.6,/,                    TTY    25300
      -T14,'P60P2   =',E13.6,/,                                          TTY    25400
      -T14,'P60P20  =',E13.6,T38,'T60T20  =',E13.6,/,                    TTY    25500
      -T14,'P7P2    =',E13.6,T38,'T7T2    =',E13.6,/,                    TTY    25600
      -T14,'P70P20  =',E13.6,T38,'T70T20  =',E13.6)                      TTY    25700
C                                                                        TTY    25800
315    FORMAT('0',T14,'NORMAL SHOCK DIFFUSER - SUBSONIC ',               TTY    25900
      -'DIFFUSER -')                                                     TTY    26000
316    FORMAT(' ',T14,'CONSTANT-PRESSURE EJECTOR - SUBSONIC ',           TTY    26100
      -'DIFFUSER',/,T14,'DATA:')                                         TTY    26200
317    FORMAT(' ',T14,'CONSTANT-AREA EJECTOR - SUBSONIC ',               TTY    26300
      -'DIFFUSER',/,T14,'DATA:')                                         TTY    26400
318    FORMAT('0',T14,'SUPERSONIC-SUPERSONIC EJECTOR - SUBSONIC',        TTY    26500
      -/,T14,'DIFFUSER DATA:')                                           TTY    26600
319    FORMAT('C',T14,'GS      =',E13.6,T38,'GP      =',E13.6,/,         TTY    26700
      -T14,'GM      =',E13.6,T38,'MWPMWS  =',E13.6,/,                    TTY    26800
      -T14,'A7A2    =',E13.6,T38,'A7A6    =',E13.6,/,                    TTY    26900
      -T14,'A8A7    =',E13.6,T38,'WPWS    =',E13.6,/,                    TTY    27000
      -T14,'M2      =',E13.6,T38,'M6      =',E13.6,/,                    TTY    27100
      -T14,'M7      =',E13.6,T38,'M8      =',E13.6,/,                    TTY    27200
      -T14,'P60P2   =',E13.6,/,                                          TTY    27300
      -T14,'P60P20  =',E13.6,T38,'T60T20  =',E13.6,/,                    TTY    27400
      -T14,'P8P2    =',E13.6,T38,'T8T2    =',E13.6,/,                    TTY    27500
      -T14,'P80P20  =',E13.6,T38,'T80T20  =',E13.6)                      TTY    27600
C                                                                        TTY    27700
320    FORMAT('0',T14,'SUBSONIC DIFFUSER DATA:')                         TTY    27800
321    FORMAT('0',T14,'RSD     =',E13.6,/,                               TTY    27900
      -T14,'GM      =',E13.6,T38,'A8A7    =',E13.6,/,                    TTY    28000
      -T14,'M7      =',E13.6,T38,'M8      =',E13.6,/,                    TTY    28100
      -T14,'P8P7    =',E13.6,T38,'T8T7    =',E13.6,/,                    TTY    28200
      -T14,'P80P70  =',E13.6,T38,'T80T70  =',E13.6)                      TTY    28300
       END                                                               TTY    28400
```

7.5.2 CLGDSP Sample Input

```
INPUT DATA FOR LASER CAVITY ANALYSIS BY NAMELIST.
CURRENT VALUES ARE:

$CAV
 GS=   1.400000     ,  M1=    2.000000     ,  A2A1=    1.000000     ,
 CO1=  0.0000000    ,  CO2=  0.0000000     ,  NPTS=                 21,
 FSP1=   10.00000    , $

 $CAV NPTS=5,FSP1=20.0 $


INPUT THE EJECTOR MODEL FROM THE FOLLOWING LIST:

"CPE" CONSTANT-PRESSURE EJECTOR
"CAE" CONSTANT-AREA EJECTOR
"SSE" SUPERSONIC-SUPERSONIC EJECTOR

CAE


INPUT THE ITERATION VARIABLE FROM THE FOLLOWING LIST:

"M6" PRIMARY NOZZLE EXIT MACH NUMBER
"A7A6" MIXING TUBE EXIT-TO-PRIMARY NOZZLE EXIT AREA RATIO
"WPWS" PRIMARY-TO-SECONDARY MASS FLOW RATIO

WPWS


INPUT DATA FOR SUPERSONIC-SUBSONIC DIFFUSER SECTION BY NAMELIST.
CURRENT VALUES ARE:

$DIFUSR
 PNSD=   1.000000     ,  A4A3=   1.000000     , $

 $DIFUSR $


INPUT DATA FOR EJECTOR ANALYSIS BY NAMELIST.
CURRENT VALUES ARE:

$EJECT2
 GP=   1.400000     ,  MWPMWS=   1.000000     ,  T60T50=   1.000000 ,
 M6=   1.010000     ,  A7A6=   10.00000     ,  WPWS=   1.000000     ,
 A8A7=   1.000000     , $

 $EJECT2 M6=4.5 $
```

7.5.3 CLGDSP Sample Output

```
               HIGH ENERGY CHEMICAL LASER SYSTEM SIMULATION
                        ONE-DIMENSIONAL ANALYSIS

                              A.L. ADDY
                              C.D. MIKKELSEN
                              W.K. SANDBERG

                              1 JANUARY 76

                    MECHANICAL ENGINEERING DEPARTMENT
                UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
                        URBANA, ILLINOIS 61801

                   ONE SOLUTION WITH ITERATION ON WPWS

           SYSTEM DATA:

POINT 1    LASER CAVITY ENTRANCE CONDITIONS

           M1     = 0.200000E+01    GS     = 0.140000E+01
           P1P10  = 0.127805E+00    T1T10  = 0.555556E+00

POINT 2    LASER CAVITY EXIT AND NORMAL SHOCK DIFFUSER
           ENTRANCE CONDITIONS

           GS     = 0.140000E+01
           M2     = 0.200000E+01    A2A1   = 0.100000E+01
           P2P1   = 0.100000E+01    T2T1   = 0.100000E+01
           P20P10 = 0.100000E+01    T20T10 = 0.100000E+01

POINT 3    NORMAL SHOCK DIFFUSER EXIT AND SUBSONIC
           DIFFUSER ENTRANCE CONDITIONS

           GS     = 0.140000E+01
           M3     = 0.577350E+00    A3A1   = 0.100000E+01
           P3P1   = 0.450000E+01    T3T1   = 0.168750E+01
           P30P10 = 0.720874E+00    T30T10 = 0.100000E+01

POINT 4    SUBSONIC DIFFUSER EXIT AND SUDDEN ENLARGEMENT
           ENTRANCE CONDITIONS

           GS     = 0.140000E+01
           M4     = 0.577350E+00    A4A1   = 0.100000E+01
           P4P1   = 0.450000E+01    T4T1   = 0.168750E+01
           P40P10 = 0.720874E+00    T40T10 = 0.100000E+01
```

7.5.3 CLGDSP Sample Output (Cont.)

```
POINT 5  CONSTANT-AREA EJECTOR SECONDARY NOZZLE EXIT
         CONDITIONS

         GS      = 0.140000E+01
         M5      = 0.646047E+00   A5A1    = 0.936583E+00
         P5P1    = 0.426036E+01   T5T1    = 0.166132E+01
         P50P10  = 0.720874E+00   T50T10  = 0.106700E+01

POINT 6  CONSTANT-AREA EJECTOR PRIMARY NOZZLE EXIT
         CONDITIONS

         GP      = 0.140000E+01   MWPMWS  = 0.100000E+01
         WPWS    = 0.265889E+01
         M6      = 0.450000E+01   A6A1    = 0.104065E+00
         P60P1   = 0.196212E+04   T60T1   = 0.180000E+01
         P60P10  = 0.250768E+03   T60T10  = 0.100000E+01

POINT 7  CONSTANT-AREA EJECTOR EXIT AND SUBSONIC
         DIFFUSER ENTRANCE CONDITIONS

         GM      = 0.140000E+01   MWMMWS  = 0.100000E+01
         WMWS    = 0.365889E+01
         M7      = 0.462037E+00   A7A1    = 0.104065E+01
         P7P1    = 0.199966E+02   T7T1    = 0.172629E+01
         P70P10  = 0.295838E+01   T70T10  = 0.100000E+01

POINT 8  SUBSONIC DIFFUSER EXIT CONDITIONS

         GM      = 0.140000E+01   MWMMWS  = 0.100000E+01
         WMWS    = 0.365889E+01
         M8      = 0.462037E+00   A8A1    = 0.104065E+01
         P8P1    = 0.199966E+02   T8T1    = 0.172629E+01
         P80P10  = 0.295838E+01   T80T10  = 0.100000E+01

         LASER CAVITY DATA:

         NPTS    =              5
         CO1     = 0.000000E+00   CO2     = 0.000000E+00
         GS      = 0.140000E+01   A2A1    = 0.100000E+01
         M1      = 0.200000E+01   M2      = 0.200000E+01
         P2P1    = 0.100000E+01   T2T1    = 0.100000E+01
         P20P10  = 0.100000E+01   T20T10  = 0.100000E+01

         NORMAL SHOCK DIFFUSER DATA:

         GS      = 0.140000E+01   PNSD    = 0.100000E+01
         M2      = 0.200000E+01   M3      = 0.577350E+00
         P3P2    = 0.450000E+01   T3T2    = 0.168750E+01
         P30P20  = 0.720874E+00   T30T20  = 0.100000E+01
```

7.5.3 CLGDSP Sample Output (Cont.)

POINT 8 SUBSONIC DIFFUSER EXIT CONDITIONS (Continued)

```
SUBSONIC DIFFUSER DATA:

PSD    = 0.100000E+01
GS     = 0.140000E+01   A4A3   = 0.100000E+01
M3     = 0.577350E+00   M4     = 0.577350E+00
P4P3   = 0.100000E+01   T4T3   = 0.100000E+01
P40P30 = 0.100000E+01   T40T30 = 0.100000E+01

CONSTANT-AREA EJECTOR DATA:

GS     = 0.140000E+01   GP     = 0.140000E+01
GM     = 0.140000E+01   MWPMWS = 0.100000E+01
A7A6   = 0.100000E+02   WPWS   = 0.265889E+01
M6     = 0.450000E+01   M7     = 0.462037E+00
P60P50 = 0.347866E+03   T60T50 = 0.100000E+01
P7P50  = 0.354522E+01   T7T50  = 0.959053E+00
P70P50 = 0.410388E+01   T70T50 = 0.100000E+01

NORMAL SHOCK DIFFUSER - SUBSONIC DIFFUSER -
CONSTANT-AREA EJECTOR DATA:

GS     = 0.140000E+01   GP     = 0.140000E+01
GM     = 0.140000E+01   MWPMWS = 0.100000E+01
A7A2   = 0.104065E+01   A7A6   = 0.100000E+02
WPWS   = 0.265889E+01   M2     = 0.200000E+01
M6     = 0.450000E+01   M7     = 0.462037E+00
P60P2  = 0.196212E+04
P60P20 = 0.250768E+03   T60T20 = 0.100000E+01
P7P2   = 0.199966E+02   T7T2   = 0.172629E+01
P70P20 = 0.295838E+01   T70T20 = 0.100000E+01

NORMAL SHOCK DIFFUSER - SUBSONIC DIFFUSER -
CONSTANT-AREA EJECTOR - SUBSONIC DIFFUSER
DATA:

GS     = 0.140000E+01   GP     = 0.140000E+01
GM     = 0.140000E+01   MWPMWS = 0.100000E+01
A7A2   = 0.104065E+01   A7A6   = 0.100000E+02
A8A7   = 0.100000E+01   WPWS   = 0.265889E+01
M2     = 0.200000E+01   M6     = 0.450000E+01
M7     = 0.462037E+00   M8     = 0.462037E+00
P60P2  = 0.196212E+04
P60P20 = 0.250768E+03   T60T20 = 0.100000E+01
P8P2   = 0.199966E+02   T8T2   = 0.172629E+01
P80P20 = 0.295838E+01   T80T20 = 0.100000E+01
```

7.5.3 CLGDSP Sample Output (Cont.)

```
POINT 8  SUBSONIC DIFFUSER EXIT CONDITIONS (Continued)


                SUBSONIC DIFFUSER DATA:

                RSD    = 0.100000E+01
                GM     = 0.140000E+01   A8A7   = 0.100000E+01
                M7     = 0.462037E+00   M8     = 0.462037E+00
                P8P7   = 0.100000E+01   T8T7   = 0.100000E+01
                P80P70 = 0.100000E+01   T80T70 = 0.100000E+01



TO RESTART PROGRAM ENTER "YES"
TO STOP PROGRAM ENTER "NO"
NO

END OF EXECUTION
```

7.6 AN EXPERIMENTAL INVESTIGATION OF THE PERFORMANCE OF A CONSTANT-AREA, SUPERSONIC-SUPERSONIC EJECTOR FOR VARIATIONS IN THE MIXING TUBE LENGTH-TO-DIAMETER (L/D) RATIO

The results presented in Section 3.0 of this report were principally for variations in primary and secondary stream Mach numbers, M_{P1} and M_{S1}, and secondary-to-primary area ratio, A_{S1}/A_{P1}. The effects of variations in the mixing tube length-to-diameter ratio were investigated only indirectly by means of the measurement of the flow non-uniformity at the mixing tube exit and the recompression pressure rise along the mixing tube wall. The need to investigate the effects of length-to-diameter ratio was recognized, and a series of experiments were conducted for an ejector configuration investigated in Section 3.0. This configuration was defined by: $M_{S1} = 2.00$, $M_{P1} = 2.50$, and $A_{S1}/A_{P1} = 0.88$; experimental data were presented for this ejector in Figs. 3.3 - 3,7, and 9. For this series of experiments, the experimental procedure was the same as outlined in Section 3.2, and the mixing tube length-to-diameter-ratios were: L/D = 5, 7.5, 10, 12.5, and 15.

The results of this investigation are presented in Figs. 7.6 - 1,2. As is evident from these figures, the overall ejector performance was nearly identical for all ejector configurations with $L/D \geq 7.5$. The largest values of P_{M3}/P_{S1} versus W_P/W_S were found for a mixing tube L/D = 10 (the configuration investigated in Section 3.0). The values of P_{M3}/P_{S1} versus W_P/W_S for mixing tube L/D =7.5, 12.5 and 15 were slightly less than those for a mixing tube L/D = 10. Ejector performance at a mixing tube L/D = 5 was significantly degraded relative to the mixing tubes with large L/D ratios. This poor performance is due to the inadequate mixing and recompression length within

the L/D = 5 mixing tube. For the longer mixing tubes, frictional losses may tend to reduce the performance more than the gains made in achieving a more uniform velocity profile at the mixing tube exit; compare, for example, the performance results for L/D = 7.5, 10, 12.5, and 15 in light of the known flow non-uniformities for an L/D = 10, Figs. 3.3 - 7,9.

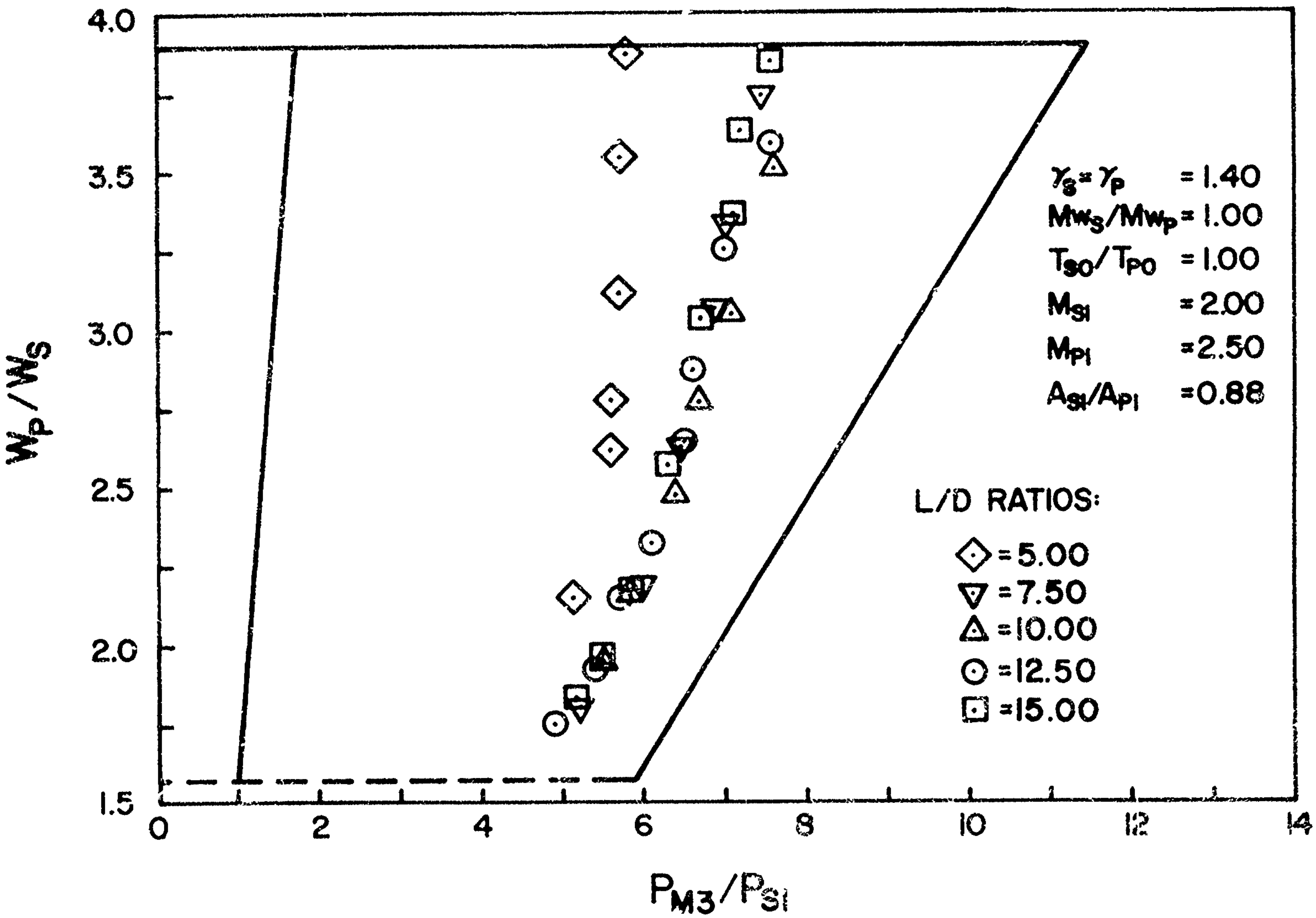

Figure 7.6 - 1. Maximum Ejector Compression Characteristics for Variations in Mixing Tube Length-to-Diameter Ratio (W_p/W_s vs. P_{M3}/P_{S1}).

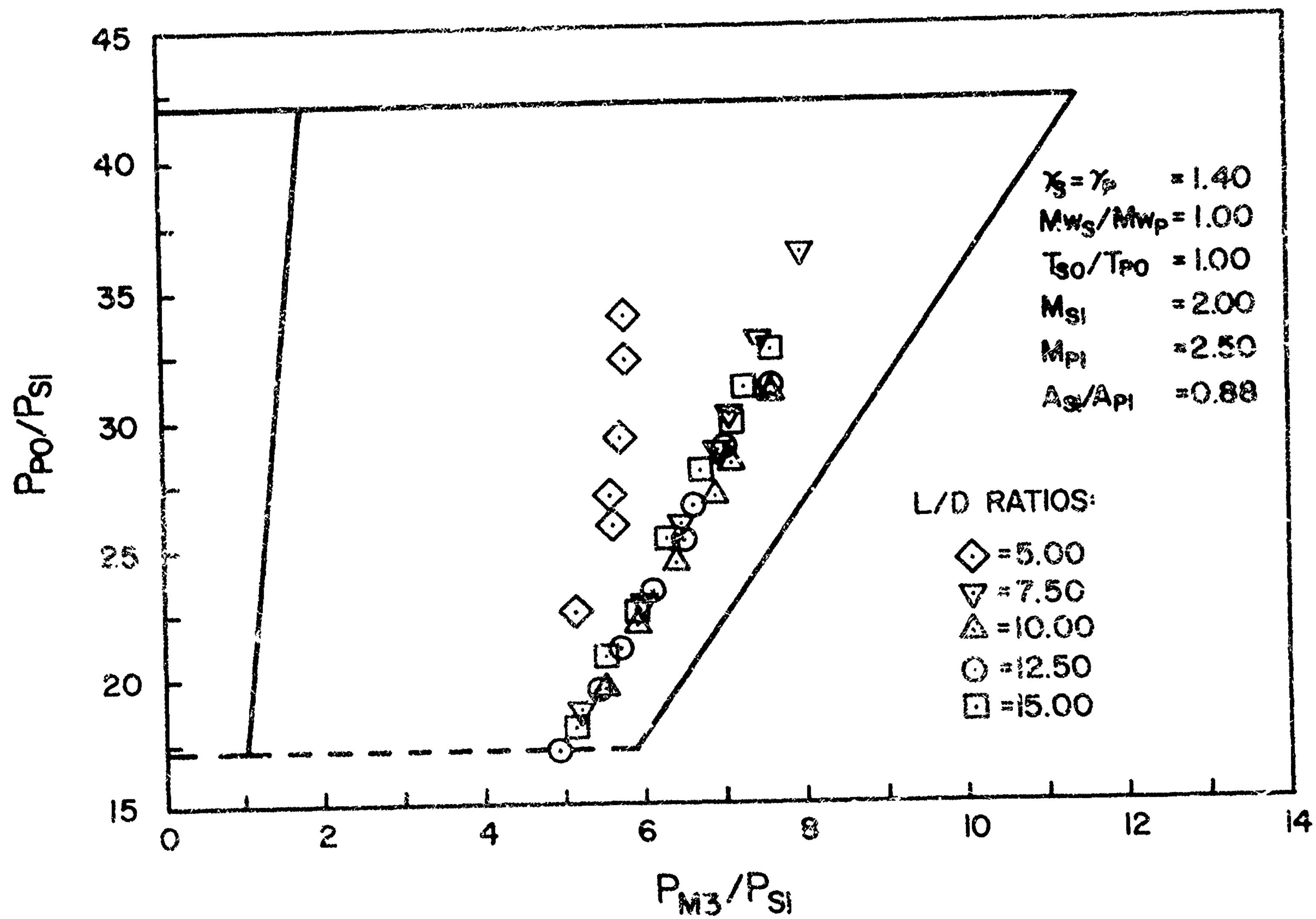

Figure 7.6 - 2. Maximum Ejector Compression Characteristics for Variations in Mixing Tube Length-to-Diameter Ratio (P_{PO}/P_{SI} vs. P_{M3}/P_{SI}).

8.0 PARTICIPATING PERSONNEL

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